THE SOIL SCIENCE SOCIETY OF FLORIDA

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1942

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ACKNOWLEDGMENTS

The Executive Committee of the Society and the entire membership wish to take this opportunity to thank President John J. Tigert for his gracious and kindly welcome and for his generous permission to use the facilities of the University of Florida campus to hold our annual meetings; also for the fine cooperation of many members of the Staff of the University and of the College of Agriculture, especially Associate Director of the Experiment Station, Mr. Harold Mowry and Dean H. H. Hume to whom we are priviledged to dedicate this volume.

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CONTENTS

		Page
Acknowledgments		2
Sustaining Memberships		2
Dedication, Dr. H. H. Hume, Dean, College of Agriculture, University of Florida		4
Guest Speaker, Dr. G. Steiner, Chief, Division of Nematology, U. S. Department of Agriculture, Washington, D. C.		6
Address: Nematodes and the Life Association of the Soil		7
Round Table Discussion—Florida's Soil Fertility Problems		
Introduction—Mr. Harold Mowry		11
From the Standpoint of Research and Extension		
1. Problems in Soil Surveying	J. R. Henderson	13
2. Truck Crops	F. S. Jamison	19
3. Other Horticultural Crops	G. H. Blackmon	20
4. Tung	F. S. Lagassee	20
5. Citrus	V. C. Jamison and T. W. Young	20
6. Pasture Crops	R. E. Blaser	26
7. Miscellaneous Farm Crops	W. E. Stokes	27
8. Discussion led by	H. G. Clayton	27
From the Growers' Standpoint	H. C. Brown	27
From the Standpoint of the Fertilizer Manufacturer	Frank Holland	28
Research in Soil Fertility as the Basis of Effective Fertilizer Control in the Broader Sense (A Communication)	J. J. Taylor	28
Symposium: Soil Fertility Investigations		
The Comparative Value of Various Nitrogen Fertilizers for Citrus —G. M. Volk, Eugene Borda and R. V. Allison		31
The Nature and Occurrence of Calcium Cyanamid Toxicity on Citrus —G. T. Sims and G. M. Volk		39
Producing Nitrogen on the Farm	George D. Thornton	46
Development and Evaluation of Methods for the Determination of Phosphorus in Everglades Peat under Various Conditions of Treatment	W. T. Forsee, Jr.	50
A Comparison of Different Sources of Phosphorus for Use on Everglades Peat	J. R. Neller	55
Phosphorus Leaching Studies in Everglades Peat under Lysimeter Conditions —W. T. Forsee, Jr. and J. R. Neller		61
The Relative Availability of Waste Pond Phosphate as a Source of Phosphorus and Calcium for Clover	G. M. Volk, G. C. Willson and R. E. Blaser	64
The Outlook for Insoluble Sources of Trace Elements under Florida Conditions	R. V. Allison	69
Symposium: Nematode Control under Florida Conditions		
Introduction	Dean H. H. Hume	71
Plant Nematodes the Grower Should Know	G. Steiner	72
Weed Host Plants of the Root-Knot Nematode Found in the 3-Year Tobacco Rotation	H. E. Bratley	118
The Natural Control of Root-Knot	J. R. Watson	121
Preliminary Observations on the Use of Dichlorethyl Ether in the Control of Nematodes	Ralph L. Miller	123
Chemical Control of Plant Parasitic Nematodes in the Soil	A. L. Taylor	126
The Control of Nematodes in the Organic Soils of the Everglades —G. R. Townsend		141
The Nematode Problem from the Soil Microbiological Standpoint —F. B. Smith and J. W. Batista		144
Some Soil Borne Insects of Interest to Florida Growers with Brief Notes on Their Control	A. N. Tissot	148
Soil Borne Diseases and Some Methods of Control	Erdman West	151
Banquet and Business Meeting		154
Meeting of Executive Committee		155
Resolutions		157
Officers of the Society (1942)		159

DEDICATION
DEAN H. H. HUME, COLLEGE OF AGRICULTURE
UNIVERSITY OF FLORIDA

So extensive are Dean Hume's contributions to Florida agriculture that it would not be possible, or even particularly appropriate, to undertake to list them at this time especially since so many of them are so well known.

It is written somewhere in the record that one of the contributing causes to the Dean's becoming interested in scientific horticulture was the pique he felt, while engaged in the nursery business as a young man, when told that azalea cuttings could not be rooted. He proceeded to root a considerable number, some of which are still growing in the nursery at Glen St. Mary.

Incidentally it is not recorded anywhere, to the knowledge of anyone who has been consulted in the matter, that the Azalea incident is the only time that Dr. Hume has been piqued. Creative action intolerant of red tape, or any other form of indolence, and an exceedingly fine mind that is well arranged and well managed at all times are highly important factors in his extensive and important accomplishments.

It is not alone his high standards of accomplishment in the field of Agricultural Science but even more particularly his great, and in fact insatiable, love of all forms of plant life and his keen interest in all factors contributing to this endless maze of natural marvels that causes the Soil Science Society of Florida to feel really honored in being able to dedicate this volume to Dean Hume.

DEAN H. H. HUME

GUEST SPEAKER

DR. G. STEINER, CHIEF, DIVISION OF NEMATOLOGY U. S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

Dr. Steiner was born in Signau, Switzerland and took his doctor's degree in Bern in 1910 where he continued as privot-docent for some time. Later he became Seessel Research Fellow at Yale and subsequently entered the Division of Nematology of the Bureau of Plant Industry of the U. S. Department of Agriculture where he is now Principal Nematologist.

As the result of many years of indefatigable work in one of the most important fields of Agricultural Science, and at the same time one that has received the very poorest sort of support from both state and federal governments, Dr. Steiner has made numerous contributions to this science, many of them of notable importance from both the scientific and economic standpoint. His brief discussion of the field of nematology starting on the opposite page and the more detailed review of the field that is presented along with many fine illustrations well illustrate his fine grasp of the field.

He is a member of many National and International Societies and, aside from his chosen field of nematology, is particularly interested in comparative anatomy, invertebrates and parasitology.

NEMATODES AND THE LIFE ASSOCIATION OF THE SOIL[1]

DR. G. STEINER[2]

I greatly appreciate the opportunity to speak before your Society on a subject which in the past has received little or no attention in soil science investigations. Although the soil scientist is well aware of the presence of a "biological factor" or a "biological component" in what he defines as "soil", his conception of the nature of this biological factor are often defective and even erroneous. Bacteria and fungi have so completely taken the stage, so far as soil biology is concerned, that the other forms of life occurring in soil have been very much neglected, and sometimes even completely ignored. Consequently I should like to remind you that the soil not only harbors bacteria and fungi, certain protozoa, earthworms, and "burrowing" animals, but that it also is the life medium for algae, turbellarians and land planarians, rotifers, gastrotrichs, nematodes, tardigardes, crustaceans, diplopods, chilopods, mites, spiders, and numerous insect forms. Some of these ignored groups are represented everywhere and usually in enormous numbers.

In considering the significance of these life forms, it should be emphasized that "life" means action and that action emanating from these forms of life is as significant as the amount of organic material, of fertilizer compounds, and of other chemical elements that eventually their dead bodies will add to the soil. During its life each of these organisms is the center of a sphere of action from which chains of activities emanate, influencing the organic as well as the inorganic environment. Food and water are taken in, a gas metabolism proceeds, excreta, secreta, and other products are deposited, and movements through the soil are performed; in short the structure as well as the composition of the soil is constantly influenced. There will be a time when soil science will know more about these components of the life association in soils, when it will be possible to point with a factual background to the significance of these life forms and the role that each plays in the complexity of processes, actions, and interactions that make a "live" soil. However, it is high time for soil science to consider the entire life component instead of only a part of it, namely bacteria, fungi, and perhaps some insects, disregarding the rest with haughty dignity as "worms".

Actually this neglected "rest" includes some groups of organisms that are highly significant not only quantitatively, but even more so qualitatively. One of these groups is the nematodes, also called eelworms, threadworms, or roundworms. Although little known, these nematodes occur wherever life can exist; in the Arctic region as well as in the

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[1] Address at Annual Banquet, Whitehouse Hotel, December 18, 1943.

[2] Principal Nematologist, Bureau of Plant Industry, Soil and Agricultural Engineering, U. S. Department of Agriculture, Beltsville, Maryland.

tropics, in hot springs and other types of fresh and salt waters, in the deep sea as well as in the red snow of high mountains where they feed on the algae tinting this snow. The soils harbor an endless number of forms, and they occur as parasites of plants, man, and practically every type of animal. Nematodes are one of the most numerous and widely disrupted groups of organisms on our globe. Their number in our agricultural soils amounts not only to millions, but often to billions per acre and, of course, this number includes many genera as well as thousands of different species. Yet this world of life is little known for various reasons. First, the soil is a difficult medium from which to collect life forms. It is a tremendous task just to collect and segregate the nematodes living in a cubic foot or cubic yard of any of our agricultural soils. But it is still more of a task to identify and classify these nematode forms and to ascertain the significance of each as a biological entity in relation to the soil and to the other members of its life association.

From a technical point of view the soil offers enormous difficulties as an environment for living organisms if it is desired to study even a single one of these nematodes in its behavior and in its life reactions within the natural medium, i.e., within soil. Even the most carefully planned experimental work may still overlook important factors present under natural conditions. Secondly, this situation is made still more complex by the fact that these organisms are themselves a difficult subject for taxonomic, anatomical, morphological, and physiological studies because of their complex structure and minute size. The third, and perhaps most lamentable, reason that nematodes do not receive their share of consideration is the fact that nematology is not taught in our educational institutions in any adequate way. Plant-parasitic or pathogenic and free-living nematodes are more or less completely ignored in zoological, parasitological, plant pathological, and soil science courses. These factors have created a situation which your society has now taken steps to remedy by planning a Symposium on nematode control under Florida conditions.

Florida soils, as far as we can judge from the samples received in our official work, unquestionably contain a rich and extremely interesting nematode fauna embracing many forms not observed in other regions of this country. It is a field for exploration, with lots of surprises, which again and again offers new and very fascinating types of structures and interrelations between organisms and their surrounding medium.

The soil nematodes constitute a group of organisms which are extremely varied in their ecological and physiological activities. For instance there are vegetarians, some even highly specialized as to their kind of plant food. There are also parasites and semi-parasites on plants. Among these some live as endo-parasites on the inside, and others as ecto-parasites on the surface of the plant host. Some are sedentary, others migratory parasites. Some are polyphagous, others show a high degree of specialization in the selection of their host plant. There are forms attacking only the roots or other subterranean parts of plants. Others live in stems, in leaves, in flowers, or in fruits of plants; and there are also other specialized types infecting only seeds. Some of

these parasites produce galls and a variety of other malformations; others cause necrotic lesions or the death of parts or the whole of a plant. Certain forms need the vascular tissues on which to live, while others attack only parenchymatous tissues. Many of these parasites have a modified or reduced digestive tract because by injecting digestive fluids from certain of their glands into the plant tissues by means of their buccal stylet they proceed to an extra-oral digestion—a digestion outside their body—with the result that the intestine is transformed into principally a storage organ for food reserve material. Still other forms migrate into the buds of plants, to the growing points, where they find the cells of tender tissues which they puncture for food, the result being that the bud or the growing point is killed outright or the young leaves, parts of flowers, or shoots are so injured that later they appear crinkled, malformed, or dwarfed, or the bud or shoot becomes blind. Other phytophagous species take advantage of lesions or cuts or other openings on plants and thus secure easy access to food. Many plant-parasitic or otherwise phytophagous forms are particularly fond of germinating seeds and young seedlings. As a matter of fact these nematode species feeding on plants often appear to have an outstanding dietary sense; they select those parts of plants which are most suitable for animal diet in that they are richest in vitamins and calories. Scribner's meadow nematode is a good example of this habit in that it selects the tissue just under the skin of a potato on which to feed, and is rarely found in the deeper parts of the tuber. The same is true of the root-knot nematodes and other species attacking potatoes, sweetpotatoes, carrots, parsnips, salsify, and similar root crops.

Nematodes of the soil, however, do not feed exclusively on higher plants, for some require algae as their food. Particularly numerous are the forms that feed on fungi, bacteria, or organic matter transformed by the action of bacteria or fungi. This relationship to bacteria, and in some degree to fungi, is of very great significance to plant pathology and to soil life. It is an important factor in successful crop production, though at present it is almost entirely ignored.

There are numerous species and genera represented in the soils which live on dead or decaying plant and animal matter. By so doing these forms come in close contact with disease organisms that in many instances have caused the death of the plant or animal on whose body the nematodes now feed. Thus disease germs, like bacteria, fungus spores, and obviously also viruses, are frequently taken in by nematodes. They pass unharmed through the intestinal tracts of the organism and thus may contribute to their dissemination. In this connection mention also should be made of the problem of the so-called soil-borne viruses, the vectors of which may be some of these nematodes. In the case of bacteria, such nematodes as rhabditids, cephalobs, diplogasters, and plectids unquestionably are principal distributors. Again and again an investigator working with these forms is impressed by the number of bacteria that are often observed in their intestinal tracts which apparently pass through them unharmed and are discharged in new locations. A few cases of even closer carrier relationship between nematodes and fungus spores are also known. For example, some two years ago an opportunity presented itself to study a leaf-spot disease occurring in Honduras on the

currant tomato. In this instance a nematode of the genus *Panagrolaimus* acted as the carrier of a rod-shaped bacterium which proved to be the causal agent of the leaf spot. The nematodes spread this bacterium through the tissues of the tomato plant, transport it up the stem to the leaves, and in turn the bacterial action appeared to cause decomposition of the tissues of the plant which then served as food for the nematode. We are convinced that the significance of these soil nematodes as carriers and distributors of bacteria and of viruses is very important. It is therefore a mistake to disregard so-called saprophytic nematodes as of no significance in our investigations on plant diseases, for it is highly possible that they are the key to a better understanding of the means by which many pathological bacteria, fungi, and viruses are spread.

These few statements may serve as examples to demonstrate how numerous are the interrelations between soil nematodes and plant life. In order to present a still more complete picture, however, it should also be mentioned that similar interrelations exist between nematodes and other animal groups of the life associations in the soil. There are nematodes that prey on other nematodes. In fact some of these predatory types have been observed in your Florida soil. Small and even large earthworms, insects of the soil and their papae and larvae, eggs of various soil organisms, rotifers or wheel animalcules, and other microscopic organisms are all known either to be directly attacked by certain forms of soil nematodes or indirectly affected by nematode-borne diseases. The pathogenic significance of certain forms hitherto termed saprozoic is also very important. They actually transmit from insect to insect highly lethal bacterial disease germs which kill the insect, and which in turn will be the source of food for these so-called saprozoic nematodes. In fact here too occur associations of bacteria and nematodes that are highly developed, highly specialized, purposeful, and fixed.

Finally, it should be mentioned that the nematodes of the soil also have their enemies, their diseases, their parasites, and other natural controlling factors. It has already been stated that there are predatory nematodes destroying plant-parasitic and other nematodes of their kind. Amoebas, tardigrades (also called bear animalcules), mites, and ants have been observed attacking and destroying nematodes. Undoubtedly fungi are effective exterminators of nematodes; the fact that there exists a considerable number of so-called nematode-catching and nematode-trapping fungi shows again how Nature often uses the most surprising methods to establish a natural balance between the components of a community of organisms. These nematode-trapping fungi are an extremely fascinating subject for study, and evidence proving their agricultural value is slowly increasing. Fungus and bacterial infections appear to comprise the bulk of diseases occurring among nematodes, although aporozoan parasites sometimes also take a heavy toll and may occur in epidemic form.

This short summary of features and problems presented by nematodes as organisms of the soil and members of the soil life association may suffice to reveal their significance and the complexity of their interrelationships with other organisms and with the non-biological components of the soil.

ROUND TABLE DISCUSSION: FLORIDA'S SOIL FERTILITY PROBLEMS

Student Union Building, Friday, December 18, 1942
9:00 A.M.
Dr. J. R. Neller, Presiding

INTRODUCTION

Mr. Harold Mowry

We have in Florida, as I see it, the most complex problems of soil fertility to be found in any like area on the globe's surface. To analyze those problems and extend the analysis to a workable solution and application is indeed complicated and at times discouraging.

I am reminded of the involved mathematical problem requiring many square yards of blackboard surface for its solution. Containing symbols and formidable formulae in disconcerting array, the final answer resolved itself into I^2. A bespectacled student who had been attempting to follow the process finally came up for air and asked what the I represented. The answer was ignorance. May our studies, analyses and interpretations not result in the answer I^2.

Our soil deposits run the gamut of scores of types that include relatively pure silicates to likewise pure calcium carbonates, colloidal clays to the sandiest loams, non-organics to peats and mucks, the overdrained to the swamp, and any intermediate admixture that swirling ocean currents, in the making of our soils, could deposit. Were all these numerous soils fertile, and here I would arbitrarily define "fertile" as capable of satisfactorily growing a climatically adapted crop without addition of materials called amendments or fertilizers, our problem would resolve itself quite easily into a simple formula resulting in the capital K—the K, of course, here stands for knowledge.

But we have no such simple condition and must be gratified when we attempt a solution of one of the thousands of minor soil fertility problems and are able to secure a small k as the answer. Our major crops are not indigenous to Florida—they have been brought from the far ends of the earth. For each of them it has been necessary to find a soil and cultural adaptability, and again for each an amended treatment has been required. We are in the midst of that amendment process with all its attendant difficulties.

Very broadly, the primary objectives are two, as I see it: First, development of knowledge that will make possible production in variety of needed agricultural materials, and, second, that this production be of such character as to return to the grower for his efforts a standard of living and a way of life comparable to that of more fertile regions and to that of other vocations.

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* Associate Director, Florida Agricultural Experiment Station, Gainesville.

We admit the lack of fertility in varying degree and kind in our soils. In that admission we have assumed a heavy responsibility—that of developing ways and means of overcoming the deficiency whatever it may be. Soils knowledge is fundamental to that effort. The usual soil analyses have been helpful but by no means can they as yet be considered as giving the final solution. Perhaps our interpretation of those analyses have been superficial, faulty, or, more likely, incomplete. It is well known that different plants respond differently to soils and other environmental conditions. This response has led to a separate branch of science with which you are all familiar, that of ecology. Horticulturists, agronomists and plant breeders in their attempts to overcome normal ecological relationships, which we are compelled to do in Florida, have made use of varied cultural practices, soil amendments, drainage and irrigation, and have bred entirely new varieties. Concurrently and paralleling those investigations, soil scientists have delved as deeply in studies of the soils themselves. But neither of the groups alone can be said to have reached a complete answer. Would it hasten the attainment of the desired objectives if these distinct methods of approach were more closely interwoven?

Plant response, either positive or negative, is usually taken as the criterion of the suitability of any treatment or environment, but how little is known of all the involved interactions that have taken place in and between plant and soil. These complex relationships and dependencies must be clarified and all contributory factors identified and evaluated. Without such knowledge we are about in the situation, to use a homely analogy, of securing a complete understanding of the electric light by examination of only the switch or the light bulb. We push the button and the light comes on; we use a given cultural practice and the plant responds. Quite simple as long as it works, but the whole system must be thoroughly known and understood in each case to improve upon it or even assure its continued satisfactory functioning.

The culture of plants normally falls into several fairly distinct groupings and, this morning, after a discussion of the soils themselves, the group fertility problems will be taken up individually by investigators in those fields. These reports cover a broad range and will be, I am sure, of timely interest.

I. FROM THE STANDPOINT OF RESEARCH AND EXTENSION

1. PROBLEMS IN SOIL SURVEYING

J. R. Henderson[1]

Soil surveys are of basic value to research and extension programs designed to solve Florida's multitudinous soil fertility problems. However, soil surveying is not without problems of its own.

The immediate objectives of soil surveying are the development of detailed soils maps and the compilation of usable soil survey reports. The soil map is of little value without the report and the report is of even less value without the map; each supplements the other and together they make a complete unit.

To obtain a good soil map we must be guided by a good, technical classification of soils. supported by reliable laboratory analyses. To develop a satisfactory soil survey report we must make use of all the available information on each unit of soil classification. If the map and report are to find their greatest usefulness they should be reduced to their simplest form consistent with the information at hand.

The purpose of this paper is to discuss some of the factors which must be considered in the solution of each of the problems noted above.

SOIL CLASSIFICATION

Soil classification should not be confused with other simpler forms of land classification. A good, detailed soil classification results in definition of specific soil units, each of which possesses a definite set of characteristics.

The individual characteristics, both internal and external, which are to be used as a basis for distinguishing one soil from another, should be defined carefully and enumerated completely. Particular attention should be given to the making of a map which shows soil units each of which possesses a particular combination of the enumerated characteristics.

Some of the more important factors which should be considered in a detailed classification of Florida soils are listed below and discussed in the pages that follow.

1. Character and origin of parent materials.
2. Depth and character of underlying formations.
3. Texture of the various horizons.
4. Color of the various horizons.
5. Consistence of the lower subsoil.
6. Depth of the lower subsoil.
7. Drainage.
8. Relief.
9. Native vegetation.

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[1] Soil Technologist, Soils Department, Agricultural Experiment Station, Gainesville.

Many of the above criteria are interrelated and the importance of each will vary from place to place. In certain areas some will be of considerable importance and, in others, of little significance from the practical point of view.

Character and Origin of Parent Materials

The source materials from which Florida soils have developed include limestones, marls, organic residues, sands and clays. The limestones may be either highly calcareous, phosphatic or sandy; the marls may be sandy, silty or clayey; the organic deposits may have developed from aquatic plants, sedges or woody materials; and the sands and clays may have been deposited, as mixtures, in marine deposits or in alluvial deposits along streams or at the base of slopes.

The parent materials may range from high to low in their content of the various sized soil particles and chemical constituents depending upon the kinds of source materials as well as upon the environmental conditions under which weathering and soil development took place.

Depth and Character of the Underlying Geological Formations

Stratification of geological deposits is quite evident in Florida. If the surface formations are of considerable thickness, the underlying materials have no bearing on soil classification. On the other hand if the surface formations are so thin that the underlying strata affects any one of the characteristics discussed below, the underlying formations should be considered a criterion of soil classification.

Texture of the Various Horizons

Each horizon or layer of a soil has a characteristic texture. Texture refers to the size and proportion of the individual soil particles.

Soil particles are divided into seven size-groups, called separates:

Separate	Diameter (mm.)
Fine gravel	2.0 to 1.0
Coarse sand	1.0 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.10
Very fine sand	0.10 to 0.05
Silt	0.05 to 0.002
Clay	Below 0.002

Since all soils contain a mixture of two or more size-groups, textural grade is used to express the percentage of the separates in the combination. The following table shows the proportion of sands, silt and clay in the 11 major textural grades.

A. Soil containing less than 20 percent clay:

1. Less than 10 percent silt and clay—sands
2. From 10 to 20 percent silt and clay—loamy sands
3. From 20 to 50 percent silt and clay—sandy loams
4. From 30 to 50 percent silt and from 30 to 50 percent sands—loam
5. More than 50 percent silt and less than 50 percent sands—silt loam

B. Soils containing from 20 to 30 percent clay:

6. Less than 30 percent silt and from 50 to 80 percent sands—sandy clay loams

7. From 20 to 50 percent silt and from 20 to 50 percent sands—clay loam
8. From 50 to 80 percent silt and less than 30 percent sands—silty clay loam

C. Soil containing 30 percent or more clay:

9. From 30 to 50 percent clay, less than 20 percent silt and from 50 to 70 percent sands—sandy clays
10. More than 30 percent clay, less than 50 percent silt and less than 50 percent sands—clay
11. From 30 to 50 percent clay, from 50 to 70 percent silt and less than 20 percent sand—silty clay

For the "sandy" textural grades (sands, loamy sands, sandy loams, sandy clay loams, and sandy clays) a modifier such as "fine" or "coarse" is used to indicate the dominant sand separate or separates:

Modifier	Dominant sand separate(s)
Coarse	Fine gravel, coarse sand
	Fine gravel, coarse sand, medium sand
Fine	Fine sand, very fine sand
Very fine	Very fine sand

The texture of soils has an important bearing on their physical nature and chemical properties. Soils of coarse texture are noncohesive, permit rapid percolation of water and have a low absorptive power for water and nutrients. On the other hand, soils of very fine texture are highly cohesive, prevent rapid percolation and are highly absorptive of water and nutrients.

The finer particles of clay separate are able to hold certain plant nutrients such as calcium, magnesium, and potassium in exchangeable form. The total amount of these bases which a soil is able to hold depends not only upon the amount but also upon the kind of clay present as well as the kind and amount of organic matter contained.

Color of the Various Horizons

Soil color is an indicator of soil conditions that are of considerable significance. Soil colors are produced primarily by organic matter, iron compounds, silica and lime.

Organic matter, whether present in large or small quantities, is an important constituent of Florida soils by virtue of its influence on other soil properties. For instance, the exchange capacity of soil organic matter may be as much as 10 times that of the clay separate. It is necessary, therefore, that the amount of organic matter present and, in some cases, its stage of decomposition be given recognition as a factor in the field classification of soils. For this purpose color terms lend themselves readily.

Soil may range in color from white, yellow or red through the grays and browns to black as their organic matter content increases. Obviously, the resulting color depends also upon the color of the mineral portion of the soil as well as upon the amount of organic matter present. In organic soils, color is often an indicator of the stage of decomposition; a raw peat usually is brown while muck is black.

Several soil colors, associated with different iron compounds, indicate the drainage conditions under which the soil developed. Red colors indicate the presence of unhydrated iron oxide and good drainage

conditions; yellow colors, hydrated iron oxide and previous conditions of poor drainage; and bluish colors, reduced iron and poor drainage. Red, yellow and gray mottlings are often the results of variable moisture conditions.

Silica and lime impart white and light gray colors. Several other constituents of Florida soils are of some importance in color production.

Consistence of the Lower Subsoil[2]

Soil consistence is a term used to describe the cohesiveness of soil particles or of aggregates of soil particles. Soil consistence is controlled mainly by the amount and kind of colloidal material present and moisture content. Such self-explanatory terms as mellow, friable, firm, plastic, brittle and tough are used to express soil consistence.

The consistence of each of the various horizons of the soil is important. However, that of the lower subsoil is of particular significance in the control of moisture conditions, erosion hazards and the penetration of plant roots.

Depth of the Lower Subsoil

In Florida, the depth of the lower subsoil ranges from only a few inches to several feet. Obviously, the depth of this material has an important bearing on the moisture conditions in the soil above.

As a general rule, the depth of the lower subsoil depends upon the texture of the material from which the soil developed. The lighter the texture the greater the depth of the lower subsoil, unless normal development has been hindered by an impervious layer or a high water table.

Drainage

Natural drainage determines not only some important soil characteristics but also the uses to which the resultant soils may be put. Under natural conditions in Florida, drainage may range from excessive to very poor.

Recognition of several functional aspects of drainage—percolation, runoff, depth of water table—is necessary in soil classification. It is felt that our terminology, in its present stage of development, is inadequate for accurate designations of the many specific conditions of drainage.

Relief

Relief is important not only as a factor in the development of soil characteristics but also as a factor in erosion and frost hazards, through its effect on runoff of water and air-drainage.

The importance of slope as a factor in soil erosion is determined in part by the internal characteristics of the soils. Very little erosion is possible on deep sandy soils even though quite rolling. On the other hand, erosion on soils of this type with impervious subsoils at shallow depths may be serious, even on moderate slopes.

Although each soil type has a characteristic range in slope, it is felt that, in areas of soils subject to erosion, slope should be mapped as a separate feature.

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[2] As used here, lower subsoil refers to the B horizon or zone of accumulation of clayey material moved down from the soil layers above.

Native Vegetation

In Florida, the character of the native plant growth is often a good indicator of certain soil conditions such as drainage and reaction and is, therefore, an important guide to the location of soil boundaries. Moreover, native vegetation is of immense practical significance as a factor in the cost of clearing land for agricultural use. Although many soil types have characteristic native plant covers, some of them may exhibit wide differences in this respect. Thus, native vegetation also should be shown on the soil map as a separate feature.

Other Characteristics

Additional factors which are of significance in the classification of Florida soils include degree of erosion, stoniness and reaction.

The degree of erosion is difficult to determine for some soils and its mapping may have to be somewhat arbitrary in many instances. Perhaps, this factor can best be given consideration as a definite feature of the soil profile.

Reaction, within broad limits, may be determined by field tests or indicated by the character of the native vegetation, kind of parent materials or the nature of underlying materials.

Most of the factors discussed above were considered in the development of Table I, which shows the various characteristics of Florida soils as they are being mapped at present. This table is not complete and is subject to extension and refinement at any time. Until the entire State has been mapped, revisions and additions will be necessary. However, it is felt that the features now recognized constitute a sound basis for the classification of Florida soils.

LABORATORY ANALYSES

A field classification of soils must be supported by analyses of various kinds. Of necessity, the major portion of the analytical work must be confined to virgin soils. However, for evaluation of various management practices in terms of soil properties cultivated soils also must be studied. Some of the more important laboratory studies are discussed below.

Mechanical Composition

Mechanical composition is revealed by mechanical analysis which is a laboratory determination of soil texture. The results are of value in two important ways: (1) they indicate the accuracy of field determinations of soil texture and (2) provide for the development of ranges in texture for each horizon of each soil type mapped.

Organic Matter

Organic matter is one of the most important constituents of Florida soils and, for a given soil under natural conditions, has a direct relationship to soil nitrogen. Since color is the usual guide to organic matter content in soil mapping, laboratory determinations of this constituent are necessary for correlation with field observations.

Moisture Equivalent

Moisture equivalent, a laboratory determination of the field moisture capacity of soils, reflects the combined effect of soil texture, soil organic matter and the chemical nature of the soil colloids. This determination is rapid and lends itself readily for characterization of each soil horizon.

Exchange Capacity

Exchange capacity is controlled by about the same factors as moisture equivalent. A careful study of this property is a further check on the validity of field separations.

Exchangeable Bases

The exchange capacity of Florida soils may be fully or only partially satisfied by bases such as calcium, magnesium and potassium. The amount of total bases as well as the amount of each present has an important bearing on the growth relationship of plants.

Reaction

Soil reaction is determined mainly by the exchange capacity and exchangeable base content of the soil material. If reaction and exchange capacity measurements are available, the amount of bases present may be arrived at with a fair degree of accuracy.

Other Determinations

The above laboratory studies when correlated with field observation will go a long way toward the characterization of the individual units of soil mapping. Under some conditions, however, complete physical, chemical and spectrographic analyses may be desirable. Of particular value under some conditions are the content of total and "available" phosphorus and trace element components.

LAND USE AND SOIL MANAGEMENT

If the soil map is to be of practical value, each soil unit must be studied from the standpoint of its management and use. In these studies, all of the available information on each soil type must be assembled and correlated with soil characteristics.

Adapted Uses

In Florida, land use assumes many forms—crops, pasture, timber, recreation, wildlife, water storage, etc. The most intensive use to which a given soil may be put should be determined and the possible alternate uses outlined. For soils suitable for crop production, the adapted crops should be determined. In the case of pasture land, the suitability of various pasture plants should be ascertained. Special adaptations for other forms of use should be arrived at in similar manner, considering all the factors which affect land use adaptations such as climate and soil management.

Soil Management

Much of the land in Florida is worthless for crop production unless one or more of the following are practiced: Drainage, liming, green

Some Important Characteristics of the Soils of Florida as Being Mapped at Present - July 1, 1942

Soil Series	Parent Materials	Field Position	Natural Drainage	Dominant Native Vegetation	Color of Surface Soil (A, horizon)	Color of Upper Subsoil (A_2 horizon)	Color of Lower Subsoil (B horizon)	Depth of Lower Subsoil [3]	Consistence of lower Subsoil	Types Being Mapped at Present	Occurs in Soils Areas (See Soil Map, Bulletin 334)
	Marine sands and clays - thick deposits Marine sands and clays over limestone Marine sands and clays over phosphatic materials Marine sands and clays over marl Phosphatic materials Phosphatic materials over limestone Limestone Marl Marl over sands and clays Organic materials over sands and clays Organic materials over limestone or marl Alluvial deposits along streams - Piedmont material Alluvial deposits along streams - Costal Plains material Alluvial deposits at base of slopes	Uplands Terraces and second bottoms First bottoms Depressions in rolling uplands	Excessive Good Imperfect Poor Very Poor	Pine, grasses Black-jack oaks, grasses Scrub oaks and sand pine Hardwoods Cabbage palmetto Cypress Bays, gums, etc. Elderberry, willow Custard apple Saw palmetto, grasses Grasses Saw grass Arrowhead, cattail, pickerel weed, bonnets, etc.	Light gray Gray Dark gray Black Brownish-gray Brown to reddish-brown Dark brown	White Light gray Gray Dark gray Black Yellowish-gray Pale yellow Yellow Yellowish-brown Brown Reddish-brown Dark brown	Gray Black Yellow Yellowish-brown Brown Orange Reddish-brown Red Gray and yellow mottled Gray, yellow and red mottled	12 inches or less 12 to 20 inches 20 to 30 inches 30 to 40 inches 40 to 60 inches 60 inches or more	Mellow, friable, slightly compact Firm, friable, moderately compact Plastic, brittle, moderately compact Tough, hard, very compact Fibrous	Sand Fine sand Loamy sand Loamy fine sand Sandy loam, deep phase Fine sandy loam deep phase Sandy loam Fine sandy loam Very fine sandy loam Loam Silt loam Sandy clay loam Fine sandy clay loam Clay loam Marl Fine sandy marl Muck Mucky fine sand Peaty muck Peat	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Alachua [2]											
Amite'											
Archer [2]											
Arredondo [3]											
Arzell [2]											
Boyboro											
Bibb											
Bladen											
Blakely'											
Blanton											
Boswell [2]											
Bowie'											
Braden [2]											
Bradenton [2]											
Brighton [2]											
Broward [2]											
Cahaba											
Carnegie [4]											
Charlotte [2]											
Chattahootchee'											
Chewacla'											
Chipley [2]											
Clewiston [2]											
Congaree'											
Copeland [2]											
Coxville											
Cuthbert											
Dade											
Davie											
Ducker [2]											
Dunbar											
Esto [2]											
Eulonia											
Eustis											
Everglades [2]											
Faceville											
Fairhope'											
Felda [2]											
Fellowship											
Flamingo [2]											
Flint'											
Fort Meade											
Gainesville											
Gandy [2]											
Grady											
Greenville											
Guin' [1, 5]											
Hallandale [3]											
Hernando											
Hyde											
Immokalee [2]											
Istokpoga [3]											
Juka'											
Izzagora [2]											
Jamison [2]											
Johnston											
Kalmia											
Keri [2]											
Lakewood											
Leaf											
Leon											
Luverne'											
Magnolia											
Manatee [2]											
Marlboro											
Myakka [2]											
Myatt											
Natchitoches [2]											
Newberry [2]											
Norfolk											
Ochlockonee											
Ochopee [2]											
Okeechobee [2]											
Okeelanta [2]											
Okenee											
Ona [2]											
Orangeburg											
Orlando											
Palm Beach											
Palmdale [2]											
Pamlico'											
Parkwood											
Perrine											
Plummer											
Pomello [2]											
Portsmouth											
Red Bay											
Rex [2]											
Rockdale											
Ruston											
St. Johns											
St. Lucie											
Sawyer'											
Scranton											
Shubuta [2]											
Stough [2]											
Sunniland [2]											
Susquehanna											
Thompson											
Tifton [4]											
Tucker [2]											
Wahadkee											

'Established series. Not recognized at time Station Bulletin 334 was published
[2] New series. Tentative name.
[3] In cases of organic soils depth of substratum is given
[4] Small iron concretions are present throughout profile
[5] Guin soils are an inseparable mixture of red and yellow soils

J.R.H.
SOILS DEPT.
JULY 1, 1942

manuring, fertilization and terracing. In fact, in many instances, soil values are determined more by management practices than by soil characteristics. This appears to be especially true in citrus and trucking sections with favorable climate for winter production of these crops.

Thus, we must collect and evaluate the effect of each management practice on land use adaptation and on crop yields and find adequate methods of bringing these influences into the over-all picture. Moreover, we must not lose sight of the possible effects of certain kinds of management practices upon adjacent soils as well as upon the well-being of the general area in which the soils are located.

THE SOIL SURVEY REPORT

The soils map, the results of laboratory studies and the data on land use and soil management must be brought together in the form of a soil survey report. If the report is to be of use to the greatest number of people, the assembled information must be presented in its simplest form. For the purpose of simplification various soil groupings and interpretive tables and maps of several kinds should prove very useful.

Since our knowledge of the characteristics, adapted uses and management requirements of Florida soils is incomplete and, no doubt, will remain so for many years to come, the detailed soil map and the accompanying report will be useful for only a limited number of years. However, it may be said with certainty that, of the two, the soil map will be accurate over a longer period of time. Thus, if preserved in its original form, it can be appraised from time to time in the light of the current information on land use and soil management. The appended chart lists a number of the important characteristics of Florida soils that are being mapped at the present time.

CHART (Insert)

SOME IMPORTANT SOILS OF FLORIDA AS BEING MAPPED AT PRESENT

(July 1, 1942)

2. TRUCK CROPS

F. S. JAMISON[3]

The need for much work on the development of improved types and varieties that are better adapted to Florida conditions was considerably emphasized in this discussion as was also the importance of giving more and more thought to essential quality relationships in the marketable products as influenced by soil fertility and other environmental factors. No formal manuscript to cover the discussion was provided. ED.

[3] Truck Crop Horticulturist, Agricultural Experiment Station, Gainesville.

3. OTHER HORTICULTURAL CROPS

G. H. Blackmon[4]

Special stress was placed on responses to trace elements that have been had during the past few years in studies with pecans and peaches, especially in the instance of zinc and the important way in which this and other elements are finding their way into the grove and orchard management programs of the State. These nutritional relationships to the incident of disease also came in for a considerable amount of discussion. No formal manuscript to cover the discussion was provided. Ed.

4. TUNG

F. S. Lagassee[5]

The brief but well-rounded discussion of tung culture in northwest Florida illustrated in a remarkably fine manner the very great advantages of gearing research programs in crop production and management to the specific soil types with which the individual or department is working. General fertility requirements on various soils were discussed briefly but particular emphasis placed on the trace element responses that have been obtained, notably to zinc and copper. No formal manuscript to cover the discussion was supplied. Ed.

5. CITRUS

Vernon C. Jamison and T. W. Young[6]

The problems presented to the research worker interested in soils used for growing citrus in Florida are not always solved by the same methods commonly used for mineral soils elsewhere. Although most of these soils are classed as inorganic, from the chemical point of view, they are essentially organic in nature. The finer, active fractions are low in clay content and dominated by organic matter. Peech (3) showed in his survey of Florida citrus soils that no single soil value determined was more closely related to grove conditions than exchange capacity and that for these soils this property depends upon the amount of soil organic matter.

Exchange capacity of a soil may be defined as its capacity to adsorb and retain certain nutrients, metallic elements such as calcium, magnesium,

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[5] Pomologist, Bureau of Plant Industry, Soil and Agricultural Engineering, U. S.D.A., Gainesville.

[6] Associate Soil Chemist and Associate Horticulturist, respectfully, Citrus Experiment Station, Lake Alfred.

and potassium in an exchangeable condition. Exchangeable condition as used here represents a state of physical balance in which these elements are more or less readily replaced into the soil solution by a chemically equivalent quantity of any one or more such elements applied to the soil. In addition to the metallic elements referred to as exchangeable bases, amonia and hydrogen can be adsorbed and replaced in the soil. The total quantity of exchangeable bases a soil can retain may be regarded as a fixed quantity. At least, it can be varied only with difficulty. Serious fertility problems connected with most of the citrus soils, especially the light sands, arise from their low exchange capacities.

This situation is further complicated by the fact that the different exchangeable bases are held by the soil with varying degrees of force. In fact, hydrogen is held more strongly than any of the nutrient bases. Since it is supplied continuously from carbonic acid when plants, animals, or microorganisms are actively growing in the soil, there is a tendency for the soil exchange complex to become dominated by hydrogen. As this element increases, the nutrient bases are displaced and tend to be depleted by leaching. This is accompanied by an acidic reaction in the soil solution. A convenient tool used in connection with the nutrient status of a soil is the measurement of pH.

When the soil has sufficient exchangeable bases present to give a neutral reaction or a pH of 7 in a 1:1 soil-water suspension, the soil is spoken of as being saturated with bases or having 100 percent base saturation. When the exchangeable bases have been completely replaced by hydrogen, most soils give a pH of about 4.5. At 50 percent saturation, the pH is generally about 5.5. So if one knows the exchange capacity and the pH, the total quantity of exchangeable nutrient bases present can be approximated. Often in practical field work a sufficient close estimation of the exchange capacity can be made from the type and color of the soil. On the other hand, fairly accurate methods should be used in determing pH. This is clearly shown when we consider that it is common for the soil pH to change only about one unit, say from 5 to 6, while the percent base saturation increases from 25 to 75 percent.

The glass electrode units now commonly used have proven quite satisfactory. However, certain precautions are necessary. Methods should be standardized. Care should be taken to keep the samples in suspension while readings are made. Otherwise, there is often a serious drift in reading with time. In addition to this, soils taken freshly from the field in a moist condition generally give a somewhat higher reading than after the same sample is first air dried and then suspended in water. For dried samples also there is a rapid increase in pH readings for several minutes after suspensions are made. For the sake of convenience air drying and then soaking for twenty minutes in a 1:1 suspension before reading has been taken as a standard procedure. For most practical work this seems quite satisfactory. However, special research problems often arise.

Thus in a recent study made by the writer of dry soils taken from under citrus trees which were known to reabsorb water only with difficulty, it was found that their pH, as determined in the usual manner, was generally more than one unit lower than that of parallel samples taken just beyond the leafdrip. Now this somewhat abnormal soil was

from "dry bodies" (1) which failed to wet even during the summer rainy season. Hence the low pH could not be attributable to excessive leaching. It was found that when the soil was wetted and air dried the pH was more than .5 unit higher than for an untreated sample. By soaking the untreated sample 22 hours the pH readings increased slowly until they were about the same as those of the pre-wetted samples. The soil taken from the middle showed about the same reading after 22 hours as after 10 minutes. The results of this experiment are shown in Table 1. Since these "dry soil bodies" are quite common, especially in older groves on light sandy soils, the wide discrepancies in pH values observed by Volk and Peech (5) between soils from under trees and from the middles may have been partly due to this peculiar soil condition. At least the pH values found in the conventional manner are not always determined by percent saturation of a soil with exchangeable bases.

TABLE 1.—The Change of pH with Time in 1:1 Soil-Water Suspensions of a Soil Sample from a Dry Body Under a Tree Before and After a Wetting-Air-Drying Treatment and Also for a Sample of Soil from the Middles Between Trees.

Time in Suspension	Soil[1] 2075D	Soil[2] 2075W	Soil[3] 2077
10 min.	5.08	5.59	6.40
20 min.	5.04	5.57	6.40
1 hr.	5.08	5.56	6.39
2 hrs.	5.23	5.61	6.39
4 hrs.	5.32	5.60	6.38
22 hrs.	5.62	5.63	6.42

[1] Soil from dry body under citrus tree untreated.

[2] Soil from dry body under citrus tree wetted and then air dried more than one month.

[3] Soil sample from middles between trees.

One might reason that since the total supply of exchangeable bases is greatest at 100 percent saturation, it would be best to maintain the soil pH at 7. However, as Peech (4) pointed out, when the soil pH exceeds 6 the formation of insoluble basic compounds will seriously decrease the availability of copper, zinc, and manganese to citrus. Also as the writer (2) has previously shown, the maintenance of pH at approximately 6 in a light sandy soil entails frequent heavy applications of dolomite.

Tentatively, it has been assumed that a pH of 5.8 is about right in that it is safe and is related to a saturation level between 50 and 75 percent. It seems more logical to maintain the base level in the neighborhood of 50 percent by small annual applications of dolomite than to allow the content of bases to fluctuate more widely by following a hit and miss procedure of less frequent larger applications.

Peech (4) has pointed out that since potassium or magnesium will replace calcium. the predominant exchangeable base, from the soil more readily than they will replace hydrogen that it should be advantageous to maintain the soil at a fairly high level of base saturation. There is some evidence that magnesium is retained better in a soil limed to pH 6 than in the corresponding unlimed soil. However, the analytical records of experimental plots kept at the Citrus Experiment Station do not seem to show that potassium is held any better at pH 6 than at 5. We need more information on the chemistry of soil potassium in our Florida soils. The amounts of exchangeable potassium found in samples from Station plots from year to year just before the spring fertilization vary from 25 to 125 pounds per acre-6 inches. Following a year of heavy rainfall the amounts found were low and after a dry year they were high, but seldom does the exchangeable potassium occupy more than 5 percent of the total exchange complex.

In spite of all the research that has been done regarding citrus fertilization with nitrogen. phosphorus, and potash on Florida soils, there is little reliable information about the efficient and economical use of N, P, and K in obtaining quality and sustained quantity of fruit. This anomalous situation arises from the fact that the dominant controlling production factors in fertilization were not the N-P-K relationships studied but the dearth of magnesium, copper, zinc. and manganese in the soil or at least the dearth of these materials in forms available to citrus trees. With the correction of the deficiency of these nutrient elements together with programs designed to maintain their supply to the trees, it seems we are now in a position to begin to solve the problems of N-P-K fertilization. Until the research workers are able to furnish reliable information regarding the best levels and ratios of these nutrients, growers will have to be content with programs that have proved safe.

Although it has generally been recommended that for fertilizer to be properly distributed an adequate amount of fine active material should fall under the tree within the leafdrip as well as in the middles, some grove and production managers claim to have obtained better results if the fertilizer was spread in the middles with little within the leafdrip. A probable explanation lies in a consideration of the physical nature of the soil beneath the trees. A moisture study was made of the soil profile under a tree following 0.85 inch of rain the day before and 5.90 inches in three weeks. A large body of dry soil existed beneath the tree extending from the trunk to the leafdrip. Moisture determinations showed the surface inch or two under the trees was considerably higher in moisture than the layer just beneath or the soil in the middles. The apparent relationship of this soil condition to a type of decline in older trees has already been reported (1). The dry soil bodies seem to reach a maximum in development, especially in the soil being most difficult to wet, under older trees, but they exist quite generally also

under younger, healthier trees. It seems likely that the development of these difficult wettable soil bodies restricts the active root zone of a tree. It has been shown that wetting and stirring the soil will make it wettable and that it will continue to be wettable after drying for at least six months. The question remains as to how often this wetting treatment must be repeated. If too often, its value is questionable both from the standpoint of expense and damage done to the roots. Also, the problem as to the cause of the dry body development itself remains unsolved. The seat of the condition is in the colloidal organic material since its separation from the sandy material with a stream of air leaves the sand readily wettable (1). The colloidal portion exhibits wetting properties similar to those of the whole soil. But what causes it—bacteria, fungi, or materials from the tree itself? Some interesting as well as practical problems are presented here.

In the east coast citrus section a soil moisture problem is of considerable importance and in need of investigation. A majority of the groves in these sections are planted on low-lying hammock, flatwoods, and prairie soils, which are relatively heavy in comparison to the sand of the ridge section. Sandy loams and loamy sands predominate in these low-lying areas. To insure adequate drainage it has been the general practice to plant the trees on beds, which vary in height from about 1 foot to 3 feet, or even 4 feet in very low areas. Since these heavy soils are quite compact and since little cultivation is generally practiced, considerable run-off of water results, particularly during heavy rains. Such groves frequently suffer severely from drought.

Most growers in these areas have made some arrangements for irrigation. The method most commonly practiced is to flood the furrows, which have been automatically provided by the bedding of the tree rows. Artesian wells are obtainable in most of these sections and hence this has proved to be a very simple and cheap method of getting water on the grove; but getting water on the grove and getting a sufficient amount of this water to penetrate to the principal root zone in the heavy soils are evidently two entirely different propositions, if one may judge by tree appearances. During droughty weather it is not uncommon to find trees continuing to wilt even after two or three days of irrigation during which time the water is held in the furrow to within 5 or 6 inches of the bed crown.

Investigations on the rooting habits of citrus on bedded groves have shown that the principal rooting zone is in about the top 12 inches of the bed. In heavy soils in groves where the water furrow is 1 foot deep there is little or no rooting across the furrow. Fibrous roots tend to be under the tree crown with some distributed along the entire length of the lateral roots. The lateral roots are found chiefly in the higher portions of the bed and grow more or less parallel to the bed.

Studies on the penetration of water into the beds on heavy soils, while under furrow irrigation, have shown that lateral percolation of water is very slow. Little water reaches the principal zone of rooting in the time generally allowed for irrigation. The principal water movement is evidently downward in the soil between the furrow where the roots are least concentrated. The vertical upward movement of

water by capillarity in these soils is also very slow, probably rarely exceeding about 1 inch in 24 hours.

From these investigations and from observations on groves while under furrow irrigation, the need of studies to find a more effective method of irrigating such groves is indicated. Before other soil fertility problems can be approached intelligently it is obvious that a means of maintaining fairly satisfactory soil moisture conditions, even during prolonged droughts, must be obtained.

While the maintenance of a satisfactory moisture content in the east coast soils appears to be of primary importance, it is by no means the only soils problem confronting the citrus grower in these regions. Since the heavy soil dominant in the coastal areas have a fairly high exchange capacity and were initially high in nutrient elements, the response of trees on these soils to an N-P-K fertilizer program was more favorable and prolonged than that of trees on the lighter ridge soils. This, evidently, was largely responsible for the idea becoming prevalent among growers on such soils that their trees would not benefit by including such elements as copper, magnesium, and manganese in their fertilizers or by the use of nutritional sprays. They have in most cases been much more reluctant to accept the newer ideas on citrus fertilizer practices which have proved so beneficial in other citrus sections of the State. However, with increased evidence of nutritional deficiencies occurring in their groves and with what is probably more convincing, the increased production obtained in other citrus sections and some few groves along the east coast by the use of copper, magnesium, manganese, and zinc. the use of these elements is now becoming much more common. There is still room for much improvement in the use of supplemental elements. While most growers are beginning to recognize their value, they are still inclined to apply them in quantities only sufficient to correct deficiencies as indicated by foliage symptoms. Larger quantities and regular applications are usually needed to increase production to a point where there will be a substantial increase in net income from the grove.

There are a few rather restricted areas on marl or other soils with the surface layers high in calcareous materials which present, as yet, an unsolved problem. The reaction of these soils is highly alkaline. Copper, zinc, manganese, and iron deficiencies frequently become severe in such areas. With the exception of iron deficiency, this trouble can be overcome satisfactorily by the inclusion of the indicated element or elements in a spray. Spray treatments, injections, and soil applications of iron in various forms have failed to give a favorable response. When iron is the controlling factor, the groves generally decline until production becomes negligible, although what little fruit is produced on these alkaline soils is generally of high quality. In some instances iron deficiency is found on noncalcareous soils with reactions around pH 5.0 to 6.0. Although the total amount of citrus affected with iron deficiency on both alkaline and slightly acid soils on the east coast is small, it still warrants the attention of one concerned with investigations on citrus nutrition.

In the past few years considerable attention has been turned to soil analyses. Probably their value has not been at all overemphasized but

sometimes misplaced. Quite frequently we receive small soil samples through the mail with a request for an analysis and recommendations. No hint as to the grove conditions will be given. The notion seems to exist popularly that there is an ideal soil situation for citrus—that research workers have learned what it is and how to fertilize so as to obtain it. Workers in the field of soil fertility generally agree that the best practical point of view is—feed the plant, not the soil. In this connection, too, it should be understood that to solve many grove problems more information is needed than can be furnished by a soil study. Even with strictly soil problems, a careful chemical analysis is often inadequate. The problem may have its solution in a study of biological relationships or an appreciation of physical phenomena such as soil moisture and temperature.

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6. PASTURE CROPS

R. E. Blaser[7]

The results of clover and grass trials on several of the more important "Flatwoods" soil types were briefly discussed with particular emphasis on all three of the major fertilizer elements, nitrogen, phosphoric acid and potash, as well as lime. The value of legumes in the pasture in supplying the most expensive of the elements, nitrogen, was carefully pointed out not only for this relationship to the grasses that follow during the summer but also for the very considerable amount of high grade forage provided by the clover during the winter months when the growth of the grass is at a minimum.

The importance of quality in forages was brought out in connection with the responses of pasture covers to some of the minor elements, notably copper and manganese under certain conditions. No formal manuscript to cover the discussion was provided. Ed.

[7] Associate Agronomist, Florida Agricultural Experiment Station, Gainesville, Fla.

7. MISCELLANEOUS FARM CROPS

W. E. Stokes[8]

The rather extensive corn, peanut and cotton fertility studies of the past were briefly reviewed and some rather general conclusions drawn contemporaneously with the discussion that followed. These related especially to the importance of maintaining the closest possible association between studies of this nature and the type and/or conditions of the soil.

The recent results with zinc on corn and other agronomic crops were cited as suggestive of much additional work to be done in this broad field of production where quality of the product in terms of its composition as a feed or as a food is even more important that a high yield which has been taken as the criterion of excellence for much too long a time. No formal manuscript to cover the discussion was provided. Ed.

8. GENERAL DISCUSSION

H. G. Clayton[9]

Due to the prevalence of labor difficulties throughout the principal producing areas of Florida at the time of the meeting the discussion as led by Mr. Clayton often trended strongly in this direction and away from the principal subject.

However, much interest was evidenced by the questions asked in two main phases in the field of soil fertility, the first being the essential nature of quality in farm products and secondly how it can be assured.

In connection with the latter phase much interest was evinced in soil or any other form of testing that would assist in determining the fertilizer requirements of growing plants in soils with definite type characteristics and adequate water supply.

[8] Agronomist and Head, Agronomy Department, Agricultural Experiment Station, Gainesville.

[9] State Administrator for Florida, Agricultural Adjustment Administration, Gainesville.

II. FROM THE GROWER'S STANDPOINT

Discussion Led by H. C. Brown[1]

While labor questions also plagued this phase of the discussion to a considerable extent, a very great amount of emphasis was given by Mr. Brown to the need for an improvement and extension of our soil testing program and the inclusion of something in the way of tissue testing as soon as possible by way of getting at whatever balance may

[1] Citrus Grower and Manufacturer, Clermont, Fla.

exist between the amount of the element that has been assimilated by the plant and the amount that exists in the soil at any particular time in a given state of availability. This need was characterized by him as one of the most outstanding in the field of soil and plant relationships at the present time.

In discussing ways and means, the symposium on the question of soil sampling and testing for pH held in Tampa in 1940 and reported in Proceedings, Volume II, pp. 9-44, was cited and suggested as a possible procedure with an appropriate extension of the scope of the tests to be made.

III. FROM THE STANDPOINT OF THE FERTILIZER MANUFACTURER

Discussion to Have Been Led by Frank L. Holland[2]

The discussion of this highly important phase of the whole subject was prevented by the fact that Mr. Holland, though present at the meeting, became ill during the morning and could not take part in the program.

IV. RESEARCH IN SOIL FERTILITY AS THE BASIS OF EFFECTIVE FERTILIZER CONTROL IN THE BROADER SENSE

Discussion to Have Been Led by J. J. Taylor

While Dr. Taylor found it impossible to meet with the group to personally lead the discussion under the important heading of control, he very kindly set forth his principal thoughts in an excellent letter on the subject which we take the liberty of including below. Ed.

(Letterhead)

STATE OF FLORIDA
AGRICULTURAL DEPARTMENT
Chemical Division

Tallahassee
December 16
1942

Dr. R. V. Allison, Head
Department of Soils
Agricultural Experiment Station
Gainesville, Florida

Dear Dr. Allison:

This will acknowledge, with thanks, your letter of December 11 inclosing copy of letter to Commissioner Mayo and tentative program for the Soil Science Society

[2] Manager, Florida Agricultural Research Institute, Winter Haven.

meeting December 18 and 19. I regret very much that I will be unable to attend these meetings. Your entire program is interesting and I am very sorry not to be able to attend, particularly since you have so kindly given me the opportunity to discuss the subject of effective fertilizer control work based on research in soil fertility. Certainly this would seem to be a sound basis to begin with to work out any changes or improvements in our regulatory program and any problem affecting the agricultural interests of the state should be approached from that angle.

For instance, take one question alone: that of the multiplicity of brands and grades of mixed fertilizers sold in the state. This subject has been under discussion in the state for years but no semblance of agreement could ever be reached on a voluntary basis for curtailing brands and grades until the matter was taken in hand by the War Production Board under war necessity. It is enlightening to note that during the registration period July 1, 1941 to June 30, 1942, approximately 10,000 registrations were made of 899 different grades. The total number of grades since July 1 this year is approximately 125 and it may be noted that quite an appreciable number of these were received before WPB Order No. 231 became effective and while they still remain on the registration books, many of them are not being manufactured as they do not come within the permitted grades. The number of grades, under this order, for Florida, which may contain chemical nitrogen is 33. A number of grades will no doubt be manufactured containing only organic nitrogen but this number will not be large.

It will be interesting to note the reaction of manufacturers and growers alike to the reduction of the number of grades of mixed fertilizers under the operation of WPB No. 231 and whether or not Florida agriculture will suffer any hardships by such a reduction. If agronomists generally are in agreement that such a limited number of grades furnish the grower ample choice to cover his fertilizer needs, I see no reason why this plan, made necessary by war needs, should not be used as a basis for revamping that part of the fertilizer regulatory program.

It is sincerely to be hoped that fertilizer manufacturers and growers alike, operating for the duration under a strict limitation of 33 grades of fertilizer containing chemical nitrogen, will be impressed with the fallacy of having hundreds of different grades and thousands of different registrations of fertilizer to meet the agricultural needs of the State. Probably in no other way could this have been brought home so forceably to the industry as by the necessity of conforming to the War Production Board order.

I do not believe the Soil Science Society of Florida could do a greater service to Florida agriculture than to study carefully the effects of the reduction of grades on the production program during the war and make their findings available to the growers and to the fertilizer manufacturers after the war is over. Should the finding of facts and the recommendation of this Society be to the effect that the industry and agriculture as a whole would benefit by a reduction of brands and grades after the war, I am sure that Commissioner Mayo and the eitire Department of Agriculture would cooperate most heartily in bringing about such changes in regulatory procedure as to make effective the recommendations of the Society.
Assuring you again of my regret at not being able to be present today,

Very sincerely yours,
/s/ J. J. Taylor
State Chemist

JJT/r

Editor's Note:—The increasing number of essential elements with which we have to deal in our soil fertility problems in Florida can go far in explaining the past confusion in fertilizer requirements of our plants and soils that has registered itself in the very great number of special brands and mixtures that have appeared on Florida markets of which the grower and fertilizer manufacturer alike complain but, like the climate, none of us have found a very definite way of doing much about it. This is especially true when considered in their necessary relations to the great

number and complexity of our soil types and the ever increasing number of plants, agricultural and others, in which the people of Florida are becoming interested.

Inasmuch as the only real unit of consideration in the building of a statewide soil fertility program that is logical and sound is the requirements of the individual plant species or types on the individual soil, that is the point at which we shall have to begin to build this picture for the grower as best we can. With the progressive development of information in a certain field, it may prove logical to combine the requirements of certain plants for a given soil or for a certain group of soils. Until this information is developed through a careful consideration of the specific plants and soils involved, however, such combinations, as a basis for practical recommendations can be regarded as only tentative, at best.

It is desired to emphasize that all this breaking down of our soils into series and types and the many, many details which it entails, is for no particular pleasure that is to be found in the process. Instead it is an effort to establish physical working units that can be distinguished with certainty in the field and systematically mapped in order definitely to establish *what* our soils are, *where* they are and *how* much of each type we have on a particular farm or in a particular township, county or State. Thus, it is only a business-like approach to the whole, involved problem of land use and one that has been ordered by our recent soil survey law as a basis for research as well as extension work in agriculture.—Ed.

SYMPOSIUM: SOIL FERTILITY INVESTIGATIONS

College of Agriculture, University of Florida

2:00 P.M., December 18, 1942

Dr. J. R. Neller, Presiding

THE COMPARATIVE VALUE OF VARIOUS NITROGEN FERTILIZERS FOR CITRUS [1]

G. M. Volk, Eugene Borda and R. V. Allison [2]

The form of nitrogen used in citrus fertilizers is receiving renewed attention, now that it is known that previous evaluations of various carriers were often based on results partially attributable to then unrecognized traces of secondary elements in the materials. With our present knowledge of the nutrient secondaries required by citrus, it is now possible to evaluate these two factors separately.

It was for the purpose of comparing the value of nitrogen in several combinations of carriers as well as the possible value of small quantities of secondary elements which they might supply, that the work described in the following report was initiated.

PLAN OF EXPERIMENT

Thirteen citrus groves were selected in which to carry out the study. Four of these were discontinued in the course of the work because of cold injury and errors in cooperation. Descriptions of the remaining nine are as follows:

Grove No.	*Variety*	*Age Years*	*Average Trunk Diameter-Inches*	*Soil Type*	*Soil pH*
1	Valencia orange	14	6.65	Norfolk fine sand	5.4
2	Pineapple orange	14	5.73	Norfolk fine sand	5.4
7	Pineapple orange	15	7.28	Norfolk fine sand	5.9
8	Marsh Seedless grapefruit	15	8.28	Norfolk fine sand	5.7
9	Pineapple orange	12	5.86	Norfolk fine sand	5.7
10	Marsh Seedless grapefruit	16	8.59	Blanton fine sand	5.9
11	Marsh Seedless grapefruit	16	9.33	Norfolk fine sand	6.0
12	Marsh Seedless grapefruit	18	7.77	Norfolk sand	5.4
13	Common grapefruit	18	8.53	Norfolk fine sand	5.6

Two blocks, each consisting of one complete replication of treatments were laid out in each grove. Each plot consisted of 16 trees, in 4 x 4 arrangement, with no border trees between plots.

The fertilizer treatments selected for comparison were as follows:

Treatment	*Source of Nitrogen for Semi-Annual Application*	*Spring Top Dressing*
1	½ from water insoluble organics ¼ from sulfate of ammonia ¼ from nitrate of soda	Nitrate of soda

[1] This work was made possible through the generous support of the E. I. Du Pont de Nemours Company, Inc., Wilmington, Del. in the form of a research assistantship which was maintained in the College of Agriculture throughout the period of the study. The preliminary discussion of this project presented by Messrs. Borda and Volk at the time of the Orlando meeting of the Society last year (Proc. Vol. III, 1941, pp. 41-43) is hereby expanded into a more detailed and final report.

[2] Chemist, Research Assistant and Department Head, respectively, Soils Department, Florida Agricultural Experiment Station, Gainesville.

2	½ from urea * ¼ from sulfate of ammonia ¼ from nitrate of soda	Nitrate of soda
3	½ from urea * ½ from sulfate of ammonia	Urea *
4	80 per cent of No. 3	80 per cent of No. 3
1X 2X 3X	Same as 1, 2, and 3, respectively, except that each received a trace element supplement each spring.	

* Supplied first year as crystal urea; thereafter in form of "Uramon" fertilizer compound.

Equal nitrogen was supplied in treatments 1, 2, and 3, and 80 per cent of this quantity in treatment 4. The ratio to potash and phosphoric acid was 4-8-8 for treatments 1, 2, and 3 and 3.2-8-8 for treatment 4. The quantity of nitrogen applied at various times and to different groves varied, depending upon the apparent needs of any particular grove, but the above ratios were always maintained within any grove. Water insoluble organics were composed of one-third fish meal, one-third bone meal, and one-third castor pomace, except in a few instances when substitution of a similar material was made necessary through local unavailability of any of the above. Phosphorus was supplied one-half from super and one-half from triple super, and potash one-half from sulfate and one-half from muriate.

The trace element supplement consisted of the following per acre application:

Copper Sulfate	25½ lbs.
Zinc Sulfate	25½ lbs.
Manganese Sulfate	25½ lbs.
Iron Sulfate	25½ lbs.
Borax	2½ lbs.

No sprays containing the above elements were to be used on any plots. However, it was found impossible to completely adhere to this spray program in some groves because of development of excessive melanose.

Fertilizers were weighed out for each individual tree and applied by hand. Treatments were begun in the fall of 1936 and continued until the spring of 1942. In the original plans it was intended that responses to treatment were to be measured by gross volume yield of fruit per tree, tree trunk circumference increases, and visual observation of fruit quality and tree health. This was later expanded to include fruit maturity tests on Groves 1, 2, and 7 during the fall of 1940 and leaf analyses for copper, manganese, and zinc during 1940 and 1941 on Grove 11, which had not received any of these elements as sprays during the period of the investigation. The maturity tests were made on samples of thirty-two fruit per plot selected for uniform size and average color break. Leaf samples were picked at random from the four inside trees of appropriate plots.

EXPERIMENTAL RESULTS

Soil Reaction

Soil reaction determinations made at the beginning and end of the investigation appear in Table 1. In all plots the pH of the soil was raised as a result of the effect of the application of 500 pounds of dolomite per ton of fertilizer. The pH is remarkably uniform for the various treatments in any one grove and is within a favorable range for citrus in all groves.

TABLE 1.—Soil pH at Beginning and End of Investigation.

Grove No.	Year	Treatment Number *						
		1	1X	2	2X	3	3X	4
1	1937	5.55	5.52	5.48	5.50	5.39	5.32	5.37
	1942	6.28	6.17	6.23	6.11	6.21	5.88	6.17
2	1937	5.48	5.43	5.41	5.43	5.39	5.40	5.36
	1942	6.18	6.09	6.18	6.09	5.81	5.76	5.93
7	1937	6.01	5.86	5.83	5.94	5.95	5.81	5.81
	1942	6.43	6.42	6.40	6.41	6.31	6.30	6.40
8	1937	5.68	5.72	5.63	5.75	5.81	5.70	5.75
	1942	6.27	6.18	6.28	6.20	6.15	6.08	6.27
9	1937	5.75	5.72	5.76	5.74	5.57	5.74	5.55
	1942	6.55	6.38	6.52	6.52	6.28	6.24	6.32
10	1937	5.93	5.83	5.90	5.93	5.99	5.85	5.83
	1942	6.31	6.19	6.37	6.30	6.21	6.09	6.26
11	1937	6.00	6.04	6.06	6.13	5.95	6.02	5.90
	1942	6.55	6.29	6.45	6.21	6.32	6.06	6.33
12	1937	5.33	5.46	5.42	5.44	5.32	5.37	5.25
	1942	5.92	6.01	6.02	5.93	5.72	5.71	5.84
13	1937	5.59	5.57	5.62	5.44	5.48	5.70	5.62
	1942	6.24	6.02	6.10	6.12	6.02	5.94	5.99

* See *Plan of Experiment*, pp. 31 and 32, for details.

Tree Growth

The effect of the various treatments on the growth of the trees is shown by data in Table 2, which gives the average tree trunk diameter increase by treatment for the period November, 1937 to December, 1941. Each figure represents the average difference obtained by measurement of approximately thirty-two trees at the beginning and end of the investigation.

An analysis [3] of the data show that without the trace element supple-

[3] Analysis by "t" test by pairing within blocks.
The use of the term "significant" refers to the 5% point and "highly significant," to the 1% point, with odds of more than 19 to 1 and 99 to 1, respectively, that such

TABLE 2.—Effect of Fertilization on Growth of Citrus.

Average Trunk Diameter Increase in Inches, from November, 1937 to December, 1941.

Grove No.	Treatment Number *						
	1	1X	2	2X	3	3X	4
1	1.36	1.40	1.29	1.39	1.24	1.32	1.25
2	1.02	1.11	1.00	1.06	1.00	.99	1.02
7	1.88	1.89	1.65	1.97	1.82	1.66	1.83
8	1.57	1.72	1.48	1.49	1.45	1.44	1.54
9	1.57	1.47	1.36	1.55	1.33	1.36	1.36
10	1.98	2.12	2.01	2.01	1.89	1.90	2.00
11	1.10	1.11	1.10	1.11	1.11	1.08	1.03
12	1.12	1.19	1.17	1.31	1.21	1.05	1.07
13	1.20	1.10	1.03	1.01	1.08	.92	.98
Average	1.422	1.457	1.343	1.433	1.348	1.302	1.342

* See *Plan of Experiment*, pp. 31 and 32, for details.

ment, treatment 1 produced "significantly" greater growth than treatments 2, 3, or 4. The rate of growth under treatment 1 was approximately six per cent greater than that of 2, 3, or 4. The latter treatments were approximately equal in their effect on growth. However, with trace element supplements, treatment 2 was equal to treatment 1 and both gave approximately eleven per cent greater growth than treatment 3. These differences are "highly significant." Application of trace elements to treatments 1 and 2 increased growth five per cent over the average for 1 and 2 with no supplements. This response to trace elements is also "highly significant."

Leaf Analysis

Table 3 shows the effect of the trace element supplement on the zinc, manganese, and copper content of the leaves of Marsh seedless grapefruit from Grove 11. The application increased the average zinc content forty-four per cent, manganese content sixty-six per cent, and copper content twenty-two per cent. The first two increases are "highly significant" and the last is "significant" by analysis of the data. Plots in this grove that were not treated with trace elements showed marked deficiency symptoms of the zinc or zinc-manganese type, while leaves of the treated plots appeared normal in every respect at all times.

differences could be due to chance and not real. It must be emphasized that the treatments within blocks laid out for this investigation were not randomized and that the analysis of the data herein presented is valid only to the extent that slope, soil, and border variation effects within any one block can be ignored.

TABLE 3.—Effect of Fertilizer Treatment on Levels of Zinc, Manganese and Copper in Grapefruit Leaves.*

Date of Sampling	Component** (Per cent or P.P.M.)	Treatment Number †					
		1	1X	2	2X	3	3X
11/23/40	Per cent Ash	11.3	11.6	11.3	12.5	13.3	12.4
	P.P.M. Zinc	23.0	40.0	25.0	39.0	27.0	33.0
	P.P.M. Manganese	20.0	32.0	19.0	32.0	20.0	30.0
	P.P.M. Copper	8.3	9.0	6.1	7.9	6.4	7.0
3/13/41	Per cent Ash	12.1	12.9	12.7	13.7	13.8	13.3
	P.P.M. Zinc	25.0	34.0	31.0	31.0	27.0	38.0
	P.P.M. Manganese	19.0	37.0	18.0	36.0	17.0	29.0
	P.P.M. Copper	4.8	4.9	3.5	4.9	3.8	5.2
7/2/41	Per cent Ash	14.0	14.9	14.7	16.1	15.4	14.8
	P.P.M. Zinc	29.0	50.0	33.0	50.0	31.0	48.0
	P.P.M. Manganese	18.0	26.0	20.0	32.0	18.0	26.0
	P.P.M. Copper	12.2	15.3	9.2	12.2	7.6	9.0
Average	Per cent Ash	12.5	13.1	12.9	14.1	14.1	13.5
	P.P.M. Zinc	26.0	41.0	30.0	40.0	28.0	40.0
	P.P.M. Manganese	19.0	32.0	19.0	33.0	18.0	28.0
	P.P.M. Copper	8.4	9.7	6.3	8.3	5.9	7.1

* Leaves plucked periodically from four inside trees of each plot.

** Analyses for copper and zinc content of the leaf samples were made spectrographically by Thomas Whitehead, Jr.: those for manganese were made chemically by G. T. Sims.

† See *Plan of Experiment*, pp. 31 and 32, for details.

Fruit Yield

The effect of fertilization on gross yield of fruit is shown by the data in Table 4. Each figure represents the average of approximately 128 individual tree harvests. An analysis of the data indicates that the effect of trace elements on yield was negligible in all treatments. In an over all comparison, treatment 2 is found to produce a yield increase over treatment 1 which is "highly significant." Broken down between oranges and grapefruit it is found to be an increase of 5.6 per cent in yield for the former and 8.5 per cent for the latter. The yields of treatments 1 and 3 are approximately equal. The yield from treatment 3 without trace elements is "significantly" greater than that from treatment 4, indicating that the amount of nitrogen supplied in the higher levels was not excessive.

Fruit Quality

There were no apparent differences in quality of fruit from any treatments as determined by visual comparisons either by research personnel or cooperators. However, in order to obtain some more exact measurement of quality, maturity tests were made on fruit from one Valencia

TABLE 4.—Effect of Fertilization on Yield of Citrus.
Average Yield in Field Boxes per Tree per Year.

Grove No.	Treatment Number *						
	1	1X	2	2X	3	3X	4
1	2.43	2.29	2.43	2.66	2.28	2.16	1.95
2	2.40	2.40	2.27	2.49	2.37	2.22	2.23
7	3.29	3.23	3.70	3.85	3.82	3.69	3.20
8	6.02	6.05	6.82	6.79	5.53	5.90	4.82
9	3.44	3.19	3.20	3.32	3.07	3.02	2.96
10	10.87	9.87	10.95	10.59	10.72	10.24	10.05
11	6.40	6.07	6.03	6.27	5.53	6.05	4.96
12	6.51	6.80	7.78	7.99	6.82	7.10	6.85
13	6.26	7.31	8.31	7.32	7.60	7.67	7.24
Average for oranges	2.89	2.78	2.90	3.08	2.89	2.77	2.59
Average for grapefruit	7.21	7.22	7.98	7.79	7.24	7.39	6.78

* See *Plan of Experiment*, pp. 31 and 32, for details.

orange grove and two Pineapple orange groves. It is evident from the data presented in Table 5, colums I, II, and III, that treatment 3 produced fruit which matured more rapidly than that from treatment 1. The effect was primarily the result of increased solids. This trend is consistent with every sampling date and in all three groves. Treatment 2 appears to be intermediate between 1 and 3 in effect on maturity, but the relationship is not consistent. Trace element supplements had little or no effect on the solids/acid ratio as can be seen by comparison of the data in columns IV and V of Table 5.

DISCUSSION

Certain differential responses to treatments, brought out by analysis of the data, merit discussion.

The fact that tree growth was more rapid under treatment 1 than treatment 2 without trace element supplements, but equal in effect on growth when the supplement was used, indicates that the organics of treatment 1 were supplying trace elements or promoting intake of them from the soil. It also indicates that as a source of nitrogen, urea was equal to the natural organics. This is further substantiated by fruit yield data.

The greater yield from treatment 2 as compared to treatment 3 can probably be attributed to the nitrate of soda top dressing in treatment 2,

TABLE 5.—Effect of Fertilization on Solids/Acid Ratio of Oranges.

	Grove No.*	Date 1940-41	Treatment Number * I Ave. 1, 1X	II Ave. 2, 2X	III Ave. 3, 3X	IV Ave. 1, 2, 3	V Ave. 1X, 2X, 3X
Solids (Brix)	1	12-28	10.65	10.65	10.81	10.75	10.67
		1-9	10.83	10.81	11.09	10.91	10.90
		1-22	10.80	10.75	11.00	10.85	10.85
		1-31	10.99	10.83	11.08	11.03	10.93
	2	10-19	9.86	10.18	10.06	10.06	10.01
		11-12	11.63	11.31	11.74	11.65	11.48
		12-5	11.90	11.79	12.02	11.88	11.94
	7	11-2	10.47	11.18	11.20	11.31	10.58
		11-21	11.44	11.87	11.85	11.81	11.64
		12-14	12.29	12.59	12.84	12.66	12.50
Per cent Acid	1	12-28	1.84	1.79	1.78	1.82	1.78
		1-9	1.72	1.62	1.69	1.68	1.67
		1-22	1.57	1.59	1.59	1.60	1.57
		1-31	1.55	1.51	1.55	1.55	1.52
	2	10-19	1.79	1.69	1.54	1.69	1.66
		11-12	1.57	1.59	1.47	1.57	1.52
		12-5	1.43	1.39	1.36	1.38	1.40
	7	11-2	1.44	1.48	1.38	1.44	1.44
		11-21	1.33	1.36	1.37	1.36	1.35
		12-14	1.20	1.18	1.22	1.18	1.22
Ratio	1	12-28	5.97	5.95	6.09	5.90	6.11
		1-9	6.29	6.67	6.59	6.48	6.56
		1-22	6.82	6.46	6.93	6.56	6.91
		1-31	7.09	7.25	7.18	7.12	7.23
	2	10-19	5.56	5.75	6.54	6.03	5.87
		11-12	7.40	7.12	8.00	7.42	7.60
		12-5	8.37	8.52	8.83	8.61	8.53
	7	11-2	7.29	7.24	8.17	7.64	7.43
		11-21	8.62	8.77	8.70	8.79	8.62
		12-14	10.21	10.49	10.60	10.61	10.26

* See *Plan of Experiment*, pp. 31 and 32, for details.

versus the urea top dressing of treatment 3. The replacement of part of the ammonium sulfate by nitrate of soda in the mixed fertilizer may enter into this consideration.

There is an apparent correlation between the source of nitrogen for spring top dressing and the utilization of trace elements from the supplement. Treatments 2 and 3, without the trace element supplement, produced equal growth increases, but when the supplement was used, treatment 2 which had a nitrate of soda top dressing produced a greater

increase than treatment 3 with the urea top dressing. Such a possible effect leads to interesting speculation on the physiological aspects of the response. Possible interference with initial intake into the plant is largely eliminated by the leaf analysis data.

The greater yield response to treatment 3, as compared to treatment 4, shows that the level of nitrogen used in treatment 3 was not excessive. The equal growth response to treatments 3 and 4 suggests that the smaller fruit yield of treatment 4 was the result of the tree growth taking priority on nitrogen utilization, leaving less for the crop of fruit than in treatment 3.

SUMMARY

Only the following general observations are thought to merit the attention of the grower or his production personnel.

1. Urea satisfactorily replaced a mixture of natural organics composed of fish scrap, bone meal, and castor pomace as a source of one-half of the nitrogen in a 4-8-8 fertilizer for gross yield and tree growth of citrus on light sands.

2. A urea spring top dressing as supplement to a 4-8-8 fertilizer deriving nitrogen equally from urea and sulfate of ammonia produced 5.4 and 7.2 per cent less gross yield of oranges and grapefruit, respectively, than did a nitrate of soda top dressing as supplement to a 4-8-8 deriving nitrogen one-half from urea, one-fourth from sulfate of ammonia, and one-fourth from nitrate of soda. It is possible that urea would be relatively more effective if applied at an earlier date to permit earlier conversion to nitrate. Time of application in this test was that commonly used for a nitrate of soda dressing.

3. Common seeded grapefruit utilized applications of water-soluble copper, manganese and zinc to Norfolk fine sand of pH 6.2 to the extent that the content of these elements in the leaves was markedly increased and leaf deficiency symptoms, thought to be a combination of the zinc and manganese pattern, completely disappeared.

4. Observations made on internal and external fruit quality merit attention, but they must be substantiated by more exact methods of study and a greater volume of data to be acceptable.

THE NATURE AND OCCURRENCE OF CALCIUM CYANAMIDE TOXICITY ON CITRUS [1]

G. T. Sims and G. M. Volk [2]

Some of the characteristics of calcium cyanamide such as its basicity and its resistance to leaching are desirable qualities for a fertilizer which is to be used under Florida conditions. However, the material is recognized as having certain peculiarities which sometimes result in plant injury when it is used incorrectly.

Calcium cyanamide is a nitrogen carrier formed by the reaction between calcium carbide and nitrogen gas to give a material holding nitrogen in the compound $CaCN_2$. Its basicity upon hydrolysis is equivalent to 70 per cent hydrated lime. In the soil it reacts with water to form calcium hydroxide and hydrogen cyanamide, the latter of which is unstable and may be further hydrolyzed to urea or, under certain conditions, polymerized to dicyanodiamide.

This experiment was initiated for the purpose of studying the effects of calcium cyanamide, hydrogen cyanamide and dicyanodiamide on citrus when applied in various manners and under different conditions.

Pot tests using hydrogen cyanamide and dicyanodiamide were set up to observe the effects of these chemicals when applied to small citrus trees growing in a light sandy soil under greenhouse conditions.

Two sour orange seedlings were planted in each of six three-gallon pots and propagated to vigorous growth. The first three pots were treated with one liter of 200, 400, and 600 p.p.m. hydrogen cyanamide solution respectively. The other three were treated with solutions in which dicyanodiamide replaced the hydrogen cyanamide. All pots were watered periodically while under observation.

After two months all dicyanodiamide treated trees showed chlorosis in proportion to the concentrations applied. The hydrogen cyanamide treated trees showed faint chlorosis immediately following treatment, but after a short time were stimulated by this source of nitrogen. Necrosis and chlorosis continued to develop on the dicyanodiamide treated trees for over five months. Figure 1 shows tree conditions after four and one-half months. During the five months period one tree growing in each of the two higher treatment levels died. Chlorosis was still apparent on the lower leaves of these trees one year later. This indicated that dicyanodiamide was either very stable in the soil or that it had induced a residual toxicity within the plant itself.

A divided root experiment was set up in the greenhouse to study the nature and extent of toxicity caused by applying high concentrations of these two materials to only a small portion of the root system of an orange tree.

[1] This work made possible through the generous support of the American Cyanamid Company, New York, in the form of a research assistantship which was maintained in the College of Agriculture throughout the period of the study.

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In this experiment two-year-old budded Hamlin orange trees were used. Each tree was planted in a 20-gallon can containing Norfolk loamy fine

Figure 1.—1, 2, and 3 are orange seedlings 18 weeks after treatment with one liter of 200, 400, and 600 p.p.m. hydrogen cyanamide solutions, respectively. 4, 5, and 6 are the same except treated with dicyanodiamide instead of hydrogen cyanamide. Note the symptoms of toxicity on leaf tips.

sand. Figure 2 shows the method by which the solutions were supplied to a small group of feeder roots on one side of each tree. The siphons were adjusted so that 50 mls. of solution passed through three quart sand-culture pots every hour. Three treatments were used, consisting of solutions containing 500 p.p.m. of dicyanodiamide, 1000 p.p.m. of hydrogen cyanamide and distilled water respectively. These were selected as a result of observations made in the foregoing experiment.

Two weeks after treatment was started leaves on the dicyanodiamide treated trees showed a distinct discoloration and crinkling. After five weeks chlorosis was apparent on both the hydrogen cyanamide and

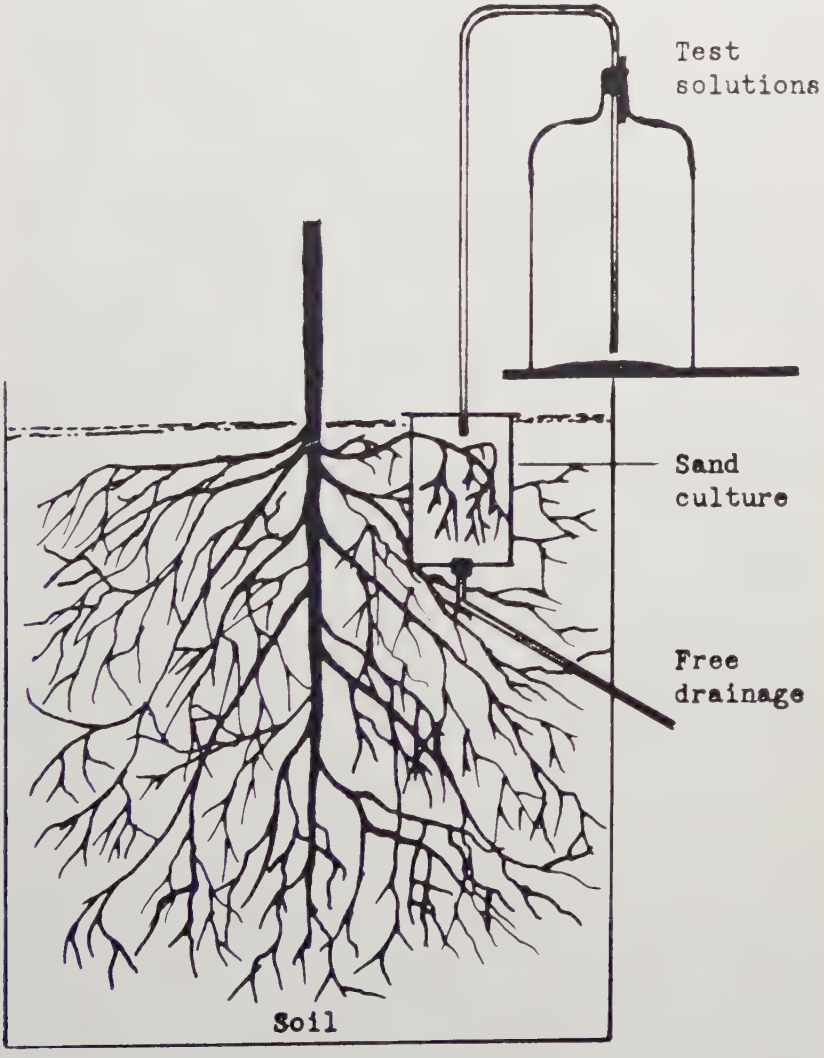

Figure 2.—Diagram of apparatus used for divided-root study.

dicyanodiamide treated trees. The latter was badly chlorotic and necrotic and had abnormally large, new leaves. During this time both trees showed a tendency to wilt, although moisture was supplied to the soil surrounding the culture pots as needed. Examination of the roots in the culture pots at this time showed that those of the check tree, which received only tap water, and those receiving dicyanodiamide were normal. The roots treated with hydrogen cyanamide were dead. They consisted of only bare, thread-like strands from which most of the cortex had wasted away.

Foliage toxicity symptoms continued to develop on both treated trees long after the treated roots and test solutions had been removed from the trees. The trees were under observation for six months longer, in which time most of the new leaves appearing on the dicyanodiamide treated tree became necrotic and shrivelled, and were finally shed. The hydrogen cyanamide treated tree showed similar symptoms, but to a lesser extent. They had recovered at the end of four months.

This experiment was repeated using different trees with practically identical results.

Because toxicity symptoms appeared uniformly over the foliage of these trees, it is assumed that a systematic poisoning had resulted from root contact with test solutions. The injury to those roots treated with hydrogen cyanamide however, also indicated localized burning. This may have stopped feeding before they could absorb a more damaging quantity of the compound. The dicyanodiamide caused no local root injury.

Greenhouse pot tests in which the pH and moisture levels were controlled were set up to study the nature and occurrence of toxicity symptoms under various conditions.

Three pencil-sized sour orange seedlings were planted in each of 56 three gallon pots containing a Norfolk fine sand and allowed time to start vigorous growth. The pots were divided into seven groups of eight pots each, representing seven previously established soil pH levels ranging from 3.6 to 7.7. Four moisture levels were then established in duplicate in each group and maintained throughout the experiment. One set of duplicate moisture levels received calcium cyanamide and the other set no treatment. The moisture levels were maintained at 20, 39, 58 and 77 per cent of the water holding capacity of the soil. Treatments consisted of 1.5 grams of calcium cyanamide applied evenly to the surface of the soil once a month until the first toxicity symptoms became apparent on the foliage.

Two weeks after the second application all treated seedlings growing in soils above pH 7.0 showed chlorosis. After three weeks, others growing in soils near neutrality exhibited the same symptoms. Finally after two months all treated trees were showing these symptoms, plus marginal necrosis or burning on those growing in soils of the higher pH levels. Figure 3 shows toxicity symptoms under two extreme pH levels. It is plainly evident that the trees growing in acid soil culture are least affected. After three months it seemed that the toxicity had run its course. Twelve of the 84 treated trees were dead. Of these only two were from soils above pH 7.0. Yet toxicity had first become apparent on

plants growing in soils having the highest pH. This indicated that regardless of the fact that they were the first to show injury, trees, growing in soil of high pH levels actually were able to recover more rapidly than those growing in soils of lower pH levels. By observation it was found that moisture had no influence on the rate of appearance of toxicity symptoms, but it evidently did have an important function in the mortality rate, because eleven of the twelve trees that died were growing in soils below the 39 per cent level.

Figure 3.—Citrus seedlings 2 months after being fertilized with two 1½ gram applications of calcium cyanamide, one month apart. Top row soil pH of 3.60 and bottom row pH of 7.56. Moisture levels, left to right, 20%, 39%, 58%, and 77%, of water holding capacity, respectively.

Field plots were laid out in bearing orange groves on six different soil types for the purpose of studying the effect of applications of calcium cyanamide at various times of the year and at various levels. The soil types selected were Eustis, Norfolk and Blanton fine sands, Bladen sandy loam, Arredonda loamy fine sand and Parkwood fine sandy loam.

Since calcium cyanamide is already being used quite successfully as a partial source of nitrogen in mixed fertilizers it was decided to use

it in this experiment as a sole source of nitrogen for some or all of the seasonal applications.

Treatments were made by hand. The amount of nitrogen different plots received per application and the time it was applied varied in the manner listed in the following table.

Treatment No.	Material	Pounds per Tree *					No. Plots per Grove
		Dec. 1940	Jan. 1941	May 1941	Aug. 1941	Nov. 1941	
1	Calcium Cyanamide	1.5	1.5	1.5		1.5	4
2	Calcium Cyanamide	1.5	1.5	1.5	2.0	1.5	1
3	Calcium Cyanamide	X**	3.0	2.25		2.25	1
4	Calcium Cyanamide	2.25	3.0	1.5		2.25	1
5	Calcium Cyanamide	X	2.25	1.5	2.0	1.5	1
6	Calcium Cyanamide	2.25	2.25	2.25		X	1
7	Urea	X	1.6	1.2		1.2	2
8	Urea	0.8	1.6	0.8		1.2	2
9	Nitrate of Soda	2.0	4.0	2.0		3.0	2
10	Nitrate of Soda	X	4 0	3.0		3.0	2

* Nitrogen content: calcium cyanamide 21%, urea 42%, nitrate of soda 16%. All trees received supplements of potash, phosphorus, and trace elements.

** X Represents two pounds sulfate of ammonia to supply nitrogen in absence of other treatment.

Toxicity symptoms appeared on trees on Eustis, Norfolk and Bladen soils in September of 1941 on all plots receiving any calcium cyanamide in the treatment and in the order 6, 2, 4, 5, 1, 3 by treatment number. Trees on Parkwood, Arredonda and Blanton types did not show injury at any time. Severe cold injury on the Bladen soil probably increased susceptibility to calcium cyanamide injury in this instance.

Toxicity symptoms appeared first on the lower leaves. The first symptom was a fading of the chlorophyll in the leaf tips. As injury progressed the leaf tips turned brown and necrotic as though scorched. In the most severe cases some leaves developed yellow chlorotic spots near the top on both sides of the midrib. There were a few leaves lost in the most severe cases. Figure 4 shows mature leaves from bearing trees in the more advanced stages of calcium cyanamide toxicity.

Development of toxicity symptoms had ceased to progress by November, so further applications of calcium cyanamide were made as previously planned. This final application did not in the least accentuate toxicity symptoms. The trees continued to improve and were completely recovered by February.

SUMMARY

Dicyanodiamide is apparently more toxic to orange seedlings than is hydrogen cyanamide.

Toxicity resulting from dicyanodiamide absorption by young orange trees will persist for as long as six months after contact with the material is cut off. It is stimulating to both roots and foliage if the plant survives the first period of most intense injury.

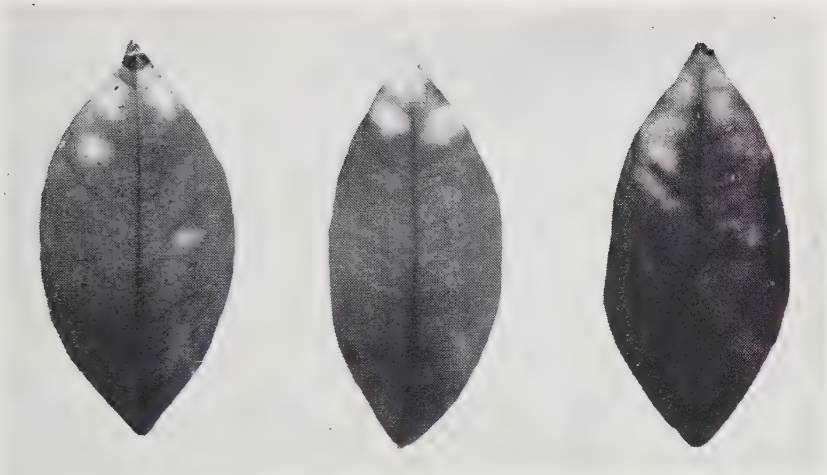

Figure 4.—Symptoms of calcium cyanamide toxicity under grove conditions.

Toxicity resulting from applications of calcium cyanamide to Norfolk fine sand at various pH levels was greatest at high pH levels and of the type suggesting that dicyanodiamide was the major cause.

Leaf symptoms of calcium cyanamide, hydrogen cyanamide, and dicyanodiamide toxicity to citrus are similar at equal intensities of injury.

Typical symptoms on mature leaves are chlorosis and necrosis of leaf tips, appearing on lowest leaves first, followed by curling up of the leaf and defoliation as injury progresses. Typical symptoms on immature leaves are chlorosis between the veins, followed by necrosis of tip, edges, and body in order, and, finally, defoliation.

Injury is more liable to result from applications of calcium cyanamide to light soils and in hot weather than to heavy soils or in cool weather.

Six to eight pounds annually of calcium cyanamide per orange tree applied in four or five applications produced injury on Eustis, Norfolk, and Bladen soil types but not on Parkwood, Arredonda, or Blanton types.

PRODUCING NITROGEN ON THE FARM

George D. Thornton [1]

Never before in the history of American agriculture has it been so urgent that Florida farmers devote all the acres possible to the production of winter legumes as a potential source of nitrogen which will inevitably be scarce in the years just ahead.

The United States Department of Agriculture reports that 450,000 tons of nitrogen, equivalent to 5½ billion pounds of nitrate of soda, is needed yearly for agricultural purposes in the United States. Only approximately 355,000 tons will be available in 1943 with much less in 1944. This means that there will be a shortage next year of 95,000 tons, which again, stated as nitrate of soda, is equal to one and a quarter billion pounds. Should the war continue into 1944 considerably less will be available from commercial sources.

This deficiency will have to be met either through the use of oil meals or by producing nitrogen with leguminous plants. With the expanding livestock industry to meet the country's war and civilian needs for livestock products, oil meals are worth approximately 2½ times as much in livestock as in crops. Consequently, very little oil meal can be used for fertilizer purposes.

Agricultural authorities throughout the country anticipate that sufficient quantities of phosphate and potash will be available for agricultural purposes, but they are urging that both winter and summer legumes be planted on a far greater acreage than ever before as an off-set to a nation-wide crisis that will be made inevitable through this nitrogen shortage.

Experiments conducted last year cooperatively by the Soils and Agronomy Departments of the Florida Agricultural Experiment Station indicate that as much as 50 to 232 pounds of elemental nitrogen can be added per acre through the use of well inoculated clovers on soils adequately fertilized with minerals.

These experiments were conducted on two widely different soil types. One was a light colored, well drained upland soil, Blanton fine sand, and the other, a low lying, dark colored soil with fair drainage, a Plummer fine sand. As a whole the yields were considerably better on the Blanton fine sand due, no doubt, to the extremely wet seasons encountered last winter. However, both areas gave reasonably good growth.

Both areas were fertilized with 1,000 pounds per acre of 18 per cent superphosphate and 200 pounds per acre of 50 per cent muriate of potash. The light colored upland soil received 1,000 pounds per acre of a good grade dolomitic limestone sufficient to bring the reaction to pH 6.5, whereas, the darker low-lyng soil required 3,000 pounds per acre of the same grade dolomitic material. This difference in amounts of limestone used on the two areas is brought about by the much higher natural acidity developed in poorly drained soils and the greater buffer capacity in these soils resulting from increased quantities of organic matter as

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indicated by their darker colors. Consequently, to get equal effects from the limestone on the two soils considerably more lime had to be added to the dark colored, low-lying type.

The above minerals were added to the soil by hand immediately after it was disced, approximately five weeks before seeding time. The soil was then disced again just prior to seeding.

Annual white sweet clover, California bur clover, black medic and white Dutch clover were used in these tests. Yields of black medic clover were not determined, consequently, this clover has been omitted from the data included in the table. Several strains of organisms were used in inoculating the various clovers and several different treatments of the seeds were made at the time of inoculation.

The effects of inoculation with strong, viable bacteria, as indicated by the yield of clover and nitrogen added per acre, are shown in Table 1.

TABLE 1.—Effect of Clover Seed Inoculation on Yield of Forage and Nitrogen Fixation per Acre on Blanton and Plummer Fine Sands.

Type of Clover	Forage Yield * (Pounds per Acre)		Nitrogen Fixed ** (Pounds per Acre)	
	Blanton Fine Sand	Plummer Fine Sand	Blanton Fine Sand	Plummer Fine Sand
California Bur Clover				
Inoculated	7,130	2,720	1,452	554
Uninoculated	3,110	766	596	147
White Dutch Clover				
Inoculated	..... †	2,090	..... †	360
Uninoculated	..... †	1,160	..... †	211
Annual White Sweet Clover				
Inoculated	3,390	2,280	468	314
Uninoculated	2,460	1,720	435	291

* Air-dry forage.

** Stated as nitrate of soda equivalent.

† No yields taken.

The results of several seed treatments at the time of inoculation, as indicated by the number of nodules per plant and the yield of clover per acre, are given in Table 2. Figure 1 shows a well-nodulated sweet clover plant resulting from a proper inoculation of the seed before planting.

In summarizing the foregoing data it may be concluded that through the use of well inoculated legumes on soils adequately fertilized with minerals, sizable quantities of nitrogen may be added to the soil. An amount equivalent to 1,452 pounds per acre of nitrate of soda was added by California bur clover on the Blanton fine sand while 554 pounds were added to the Plummer fine sand. The exceptionally wet season of 1941-42 very probably accounts for the considerable greater yields on the Blanton fine sand.

The plants used for analysis were taken at the late bloom stage.

TABLE 2.—Effect of Various Supplements Applied at the Time of Seed Inoculation on Nodulation and Yield of Forage on Three Different Types of Legumes Growing on Two Different Soils.

Treatment	California Bur Clover				Annual White Sweet Clover				White Dutch Clover			
	Average Number of Nodules per Plant		Forage Yield * (Pounds per Acre)		Average Number of Nodules per Plant		Forage Yield * (Pounds per Acre)		Average Number of Nodules per Plant		Forage Yield * (Pounds per Acre)	
	Blanton	Plummer	Blanton	Plummer	Blanton	Plummer	Blanton	Plummer	Blanton	Plummer	Blanton	Plummer
Not inoculated	3.5	4.7	3,110	766	3.1	5.2	2,450	1,720	.0	4.7	‡	1,160
Inoculated, No. treatment	4.5	9.6	7,130	1,050	10.1	8.1	3,620	3,000	11.3	10.3		2,090
Inoculated, S **	‡	‡		‡	7.8	11.6	4,550	2,930	9.3	8.4		2,040
Inoculated, S-P †	2.9	5.0	3,580	490	10.7	11.9	5,300	2,560	9.0	11.5		2,040
Inoculated, S-PO_4 ††	2.9	2.4	2,560	1,120	13.3	15.9	4,090	2,090	18.8	15.9		2,790

* Air-dry forage.

** S—3 per cent sugar solution.

† S-P—3 per cent sugar solution and peanut meal.

†† S-PO_4—3 per cent sugar solution and 1 per cent potassium phosphate.

‡ No record taken.

Squares for yield determinations were taken slightly earlier, consequently, the sweet clover was not as far advanced and correspondingly lower yields were obtained.

Treatments made at the time of inoculation were (1) seed moistened with a 3 per cent sugar solution, (2) seed moistened with 3 per cent sugar solution and then rolled in peanut meal, (3) seed moistened with a mixture of a 3 per cent sugar solution and 1 per cent K_2HPO_4 solution. None of the treatments gave consistent advantages over inoculation in the usual manner. However, all of the inoculated plots gave significant increases in yields over the uninoculated, with the exception of the California bur clover treated with the sugar-phosphate solution on Blanton fine sand and sugar and peanut meal on Plummer fine sand.

These clovers are ordinarily thought of as pasture plants. However, with the exception of white Dutch clover, all will give fair growth on the better agricultural soils of the northern half of the state. They should be planted in late November or early December, if the season permits, and may be turned under in late March or early April.

Figure 1.—The roots of well-nodulated sweet clover—"The farmer's own nitrogen factory."

There may be other legumes suited to certain localities that can be more satisfactorily used for "nitrogen factories on the farm." However, this report gives some indication of what may be accomplished with suitable plants, adequately supplied with minerals and properly inoculated with the nitrogen-fixing organisms.

In all of this it should be remembered that to plant a legume, improperly inoculated, is no better than planting a non-legume.

DEVELOPMENT AND EVALUATION OF METHODS FOR THE DETERMINATION OF PHOSPHORUS IN EVERGLADES PEAT UNDER VARIOUS CONDITIONS OF TREATMENT

W. T. Forsee, Jr.[1]

In a previous publication (2) relative to the determination of nitrogen, phosphorus and potassium in Everglades peat soils, the author described the method then in use for phosphorus determinations. This method consisted of the extraction of the soil with 0.3 *N* hydrochloric acid, development of the molybdenum blue color on an aliquot of this extract using stannous oxalate as the reducing agent, and reading the amount of phosphorus directly by a visual comparison with a previously calibrated set of standard colors. This procedure was found very satisfactory for soils medium to high in phosphate and for soils that had been fertilized with acid phosphates.

For soils low in phosphate this procedure was not satisfactory. The light blue color was difficult to match accurately and the shade of blue was somewhat variable depending apparently upon the amount of stannous oxalate used. After trying several procedures for developing the molybdenum blue color, one based upon the method of Dickman and Bray (1) was finally adopted. The concentration of chloride and molybdate ions are held within definite limits and a freshly prepared stannous chloride reagent is used for reduction. The blue color is not affected by chlorides or by ferric ion and the color is stable for at least thirty minutes. A photoelectric colorimeter is used for comparison of colors and the results are highly reproducible even for very low amounts of phosphorus.

When the soils tested had been fertilized with phosphate from sources other than acid phosphates the relative values for phosphorus were not at all consistent nor were they in line with obvious crop responses. Several extracting solutions other than the 0.3 *N* hydrochloric acid were tried. These included hydrochloric, sulfuric and acetic acids of various concentrations and several acetic acid solutions buffered to different pH levels with sodium acetate. A 0.5 *N* acetic acid solution was chosen from the trials because of its relatively consistent results.

A series of tests was made on soil samples collected from plots which had been fertilized for several years with different phosphate sources. Table 1 shows a comparison of results obtained with three extracting solutions, 0.3 *N* hydrochloric acid, 0.5 *N* acetic acid, and 0.002 *N* sulfuric acid-ammonium sulfate (3) buffered solution. The phosphorus analyses of leaf samples of shallu growing on these plots at the time the soil samples were collected and phosphorus in the juice of F31-962 sugar cane are listed in the table. The shallu samples were collected at the same time as the soil samples. The sugar cane samples were collected

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TABLE 1.—Comparison of Three Soil Extracting Solutions and Correlation of Phosphorus Found in Soil Extracts and in Plant Samples.

Plot No.	Treatment	pH	Pounds P. per A. Extracted by:			Phosphorus Content	
			0.3N HCl.	0.002N H_2SO_4	0.5N HOAc.	Shallu Leaves* (Percent)	Cane Juice (ppm.)
1	Check	5.80	24	2.0	2.0	0.25	41
3	NK	5.65	35	3.5	3.2	0.32	46
4	NPK—16 per cent superphosphate	5.80	63	7.0	7.1	0.46	159
5	NPK—45 per cent superphosphate	5.85	87	5.0	4.6	0.36	122
6	NPK—Rock phosphate	5.80	84	3.1	2.8	0.32	98
7	NPK—Basic slag	5.80	84	3.3	3.4	0.46	78
8	NPK—Colloidal phosphate	5.65	81	2.7	1.9	0.33	52
15	NPK—16 per cent superphosphate plus lime	5.90	36	4.5	5.2	0.44	130
16	NPK—16 per cent superphosphate plus sulphur	5.20	34	5.0	4.6	0.46	213

* Oven dry material.

and analyzed the previous year. The 0.3 *N* hydrochloric acid extraction was made by shaking 1 teaspoon of air dry soil with 10 ml. of solution for 1 minute; the 0.5 *N* acetic extraction was made with the same soil to solution ratio and shaken 2 minutes; the 0.002 *N* sulfuric by shaking 1 teaspoon of soil with 75 ml. solution for 1 hour. All were filtered immediately through Whatman No. 32 filter paper. The results obtained by extracting with hydrochloric acid were not at all consistent with the results of leaf and juice analyses. This gives an indication of the unreliability of this procedure on soils where different sources of phosphate have been used. The 0.002 *N* sulfuric and 0.5 *N* acetic gave values which agreed closely with each other and the relative differences were fairly consistent with those of the plant and juice analyses.

It might be stated here that the purpose of this investigation was not to find a procedure for determining the absolute amount of available phosphorus in a soil. That, of course, would be very desirable. However, if a procedure will give relative values which are in line with crop response and these values have been correlated with crop response, then we have something on which fertilizer recommendations may be based.

Table 2 shows the good correlation of phosphorus in the soil as obtained by 0.5 *N* acetic acid extraction and phosphorus in sugar cane juice, F36-273. These samples of soil and cane were collected at the same time from four fertility plots.

TABLE 2.—Phosphorus in Soil and Cane Juice from Sugarcane Fertility Plots, Section 10, Everglades Experiment Station.

Plot No.	Treatment	pH of Soil	Phosphorus Extracted from Soil, lbs. per A.*	Phosphorus in Juice (ppm.)
2	No phosphate	5.40	3.9	72
4	150 lbs. 44 per cent Superphosphate	5.50	8.5	144
5	528 lbs. Rock phosphate	5.30	5.2	91
6	440 lbs. Basic slag	5.55	4.8	78

* With use of 0.5N acetic acid as extracting solution.

Examples of excellent correlation between soil tests and tissue analyses of corn growing on these soils is shown in Table 3. Note the low phosphate in both soil tests and tissue tests for treatments 1 and 12 where the corn was obviously suffering from phosphorus deficiency. Phosphorus deficiency symptoms were also found in corn from the field of a local grower. The growth symptoms were substantiated by the tissue tests but not by the soil tests. In this case the pH of the soil was above normal due to previous burning. Therefore, where the soil pH is not normal this soil test will not provide an index of phosphorus availability. Tissue tests must be used in such instances.

In order to check the recovery of added phosphorus, a series of standard soil samples were prepared. Six inch profile samples of soil were collected in cylinders of known volume. The volume samples

TABLE 3.—Phosphorous Content of Soil and Plant Tissue Samples Taken from Phosphate Source Plots, Everglades Experiment Station.

Sample No.	Fertilizer Treatment	Plant Symptoms	Soil pH	Phosphorus	
				lbs. per A. in Soil*	ppm. in Tissue**
1A	K	Plants yellow and stunted. Purple areas on leaves.	—	2.6	57
1B	K		—	2.0	35
1C	K		—	1.8	56
1D	K		—	1.7	54
2A	PK (super)	Green color. Good growth. No evidence of phosphorus deficiency.	5.5	7.2	86
2B	PK (super)		5.6	5.5	100
2C	PK (super)		5.8	6.0	91
2D	PK (super)		5.7	6.5	86
3A	2 PK (super)	Excellent growth. Perceptibly better than 2.	5.7	12.4	106
3B	2 PK (super)		5.8	13.2	109
3C	2 PK (super)		5.8	10.7	115
3D	2 PK (super)		5.9	10.7	125
12A	PK (Colloidal)	Symptoms much the same as 1.		2.2	64
12B	PK (Colloidal)			1.6	50
12C	PK (Colloidal)			1.4	44
12D	PK (Colloidal)			2.0	46
1C	From field of a commercial grower	Very poor. All symptoms of P deficiency	7.6	16.5;15.7	51;47
2C	From field of a commercial grower	Good corn.	6.8	9.8;10.0	92;84

* As extracted by 0.5N acetic acid solution.

** On fresh weight basis. The tissue samples were taken at cross sections of the lower portion of the stalks.

were thoroughly mixed, air dried and sieved. This bulk sample was divided into equal parts by weight and a weighed amount of 44% superphosphate added to correspond to a calculated application in pounds of phosphorus per acre.

The phosphorus tests on this series of prepared standard soil samples are recorded in Table 4. The average recovery of the phosphorus of the acid phosphate added to the soil was 22 per cent for all amounts above 5 pounds per acre. Probably the difficulty of accurately adding such a small amount as five pounds accounts for the apparent low recovery of sample D-1.

A test on this same series of samples was used to determine whether or not there was any material in the soil extract that interferred with the phosphorus determinations. The procedure for the soil tests was to take 1 ml. of extract, add 5 ml. distilled water and 1 ml. molybdate reagent. Mix and add 0.5 ml. stannous chloride reagent and shake immediately. Read the color after 5 minutes. This procedure was compared with the results obtained by taking 2 ml. of extract and one less

TABLE 4.—Phosphorus Tests on a Series of Prepared Standard Soil Samples

Sample No.	Phosphorus Added to Soil, Lbs. per A.	Phosphorus Found by Analysis, Lbs. per A.*	Phosphorus Recovered** Lbs. per A.	Phosphorus Recovered (per cent)
D-0	0	6.5	—	—
D-1	5	7.1	0.6	12
D-2	10	8.5	2.0	20
D-3	20	10.5	4.0	20
D-4	40	16.0	9.5	24
D-5	60	20.3	13.8	23
D-6	80	23.7	17.2	21
D-7	100	28.5	22.0	22

* As extracted by 0.5N acetic acid solution.

** Calculated by subtracting 6.5 from the phosphorus found by analysis.

ml. of water. Table V shows this comparison. Since the p.p.m. of phosphorus in the extract obtained from a one or two ml. aliquot was the same. there were certainly no interfering substances in the extract. Table 5 also shows the recovery of phosphorus added in solution to the extract. Good recovery of added phosphorus was obtained from all the extracts.

TABLE 5.—Interference of Materials Present in Extract and Recovery of Phosphorus Added to the Extract.

Sample No.	Tests on Extract		Extract + 3.0 ppm. Phosphorus		
	1 ml. Aliquot P (ppm)	2 ml. Aliquot P (ppm)	P Found (ppm)	P Recovered (ppm)	Per cent Recovered
D-0	2.1	2.0	5.0	2.9	97
D-1	2.2	2.2	5.1	2.9	97
D-2	2.7	2.6	5.6	2.9	97
D-3	3.3	3.3	6.3	3.0	100
D-4	4.8	5.0	7.8	3.0	100
D-5	6.5	6.6	9.6	3.1	103
D-6	7.6	7.6	10.5	2.9	97
D-7	8.8	—	11.8	3.0	100

ACKNOWLEDGMENT

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A COMPARISON OF DIFFERENT SOURCES OF PHOSPHORUS FOR USE ON EVERGLADES PEAT

J. R. Neller [1]

Phosphates for use as fertilizers may be roughly divided into two groups. One of these comprise the more insoluble sources such as ground raw rock phosphate or floats and the naturally finely divided form known as colloidal phosphate or waste pond phosphate. In the second group are the chemically treated acid or superphosphates. These contain soluble phosphorus ranging from 16 to 48 per cent P_2O_5. Basic slag is intermediate with respect to this solubility factor.

As a part of the study relating to phosphate fertilizers by the Everglades Experiment Station attention has been given to some of these sources of phosphate. Thus, included among the fertilizer plots of one series are those listed as No. 3 to 8, inclusive, in Table 1. Of these plots treatment 3 received nitrogen, potash and secondary elements but no phosphate. Treatments 4 and 5 were treated with the soluble phosphates in addition to the basic fertilizer added as per Treatment 3. Treatments 6, 7 and 8 were of the more insoluble phosphates referred to in the first group, above.

The basic fertilization of these plots was at the rate of 1,200 pounds per acre of a 6-12-12 mixture. The nitrogen sources in this mixture were derived from ammonium suphate and sodium nitrate in equal parts. The

TABLE 1.—Effect of Source of Phosphorus on the Yield* of Dallis Grass on Everglades Peat.

Year	Source of Phosphate and Treatment No.**					
	None	Superphosphate		Rock Phosphate	Basic Slag	Colloidal Phosphate
		18 percent	44 percent			
	3	4	5	6	7	8
1931-32	3.733	3.818	4.288	4.419	3.819	3.880
1933	8.854	10.675	11.105	11.817	11.423	10.612
1934	3.355	5.303	5.190	5.895	4.883	5.023
1935	5.980	6.385	6.390	6.440	7.175	6.460
Total	21.922	26.181	26.973	28.571	27.300	25.975
Average	5.481	6.545	6.743	7.143	6.825	6.494

* As tons of oven-dry forage per A.

** From the phosphate source series at the Everglades Experiment Station started in April, 1929. All plots in this series received nitrogen, potash and secondary elements. A total of 25 different crops were studied in the course of the experiment.

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floats or ground rock phosphate of Treatment 6 was applied at a rate equal to four times the amount of phosphorus used in treatments 4 and 5. Basic slag and colloidal phosphate (Treatments 7 and 8) were applied at rates of 1½ and 2 times, respectively, the amount of phosphorus in the superphosphate treatments of 4 and 5. The floats contained 24, basic slag 10 and colloidal phosphate 26.4 per cent, respectively, of P_2O_5.

Table 1 records the air dry weight in tons per acre of Dallis grass obtained from these plots for the year 1931-1935 inclusive. These are averages from duplicate plots. It may be observed that each of the five different kinds of phosphates increased the tonnage over that obtained where no phosphate was used (Treatment 3). It is also evident that equally good results were obtained from the more insoluble phosphate treatments 6, 7 and 8 as from those where the superphosphates were used in treatments 4 and 5. Similar results were obtained from the growth of carpet grass on these same treatments for the same periods.

TABLE 2.—Effect of Source of Phosphorus on the Phosphate Content* of Dallis Grass Grown on Everglades Peat.

Sample Series No.	Date of Sampling	Source of Phosphate and Treatment No.**			
		None	Superphosphate (18 per cent)	Rock Phosphate	Basic Slag
		3	4	6	7
376	6/17/31	0.53	0.68	0.59	0.51
420	9/7/31	0.59	0.87	0.60	0.59
438	1/6/32	0.45	0.56	0.56	0.54
462	7/1/32	0.53	0.67	0.63	0.60
686	5/17/34	0.40	0.68	.....	.....
702	7/2/34	0.36	0.86	.....	.....
799	5/22/35	0.39	0.53	0.66	0.51
822	7/3/35	0.44	0.68	0.59	0.61
853	10/21/35	0.51	0.78	0.69	0.65
892	5/5/36	0.23	0.50	0.50	0.51
905	6/17/36	0.32	0.67	0.60	0.52
918	8/11/36	0.32	0.76	0.62	0.66
941	10/15/36	0.37	0.89	0.82	0.75
989	5/10/37	0.23	0.71	0.82	0.62
1100	3/22/38	0.36	0.47	0.53	0.38
Average		0.402	0.687	0.632	0.573

* Recorded as per cent P_2O_5 on oven dry basis.

** From the same phosphate source experiment referred to in Table 1.

In Table 2 there is a record of the phosphate content of samples of Dallis grass obtained from the plots referred to in Table 1. Referring to the average analyses of these samples it may be observed that grass from the plots treated with 18 per cent superphosphate contained 71 per cent more phosphorus than the grass grown on the plots which received no phosphate. The phosphorus content of grass fertilized with

TABLE 3.—Effect of Source of Phosphorus on the Yield of Certain Vegetable Crops Grown on Everglades Peat.

Treatment No.*	Phosphate Source	Peas—Vines Only (Lbs. per A.)	Potatoes (Bu. per A.)	Carrots (Tons per A.)
3	None	818	300	6.493
4	Superphosphate (18 per cent)	871	405	8.188
5	Superphosphate (44 per cent)	1,003	432	7.830
6	Rock phosphate	554	385	6.494
7	Basic slag	845	353	7.623
8	Colloidal phosphate	550	359	6.453

* From the same phosphate source experiment referred to in Table 1.

rock phosphate was 58 per cent and that with basic slag 40 per cent higher than that of the grass which received no phosphate (Treatment 3).

At different times vegetables were grown adjacent to the grass plots on these phosphate source treatments. Peas (Table 3) were found to grow better where the acid or soluble phosphates were used. Potatoes also produced higher yields when treated with superphosphates. This was also true of carrots, except in the case of the basic slag (No. 7) treatment. The weight of pea vines (the peas on these small plots having been harvested by birds) was likewise greater in the presence of basic slag than it was with rock or colloidal phosphates.

TABLE 4.—Effect of Source of Phosphorus on the Phosphate Content of Certain Vegetable Crops Grown on Everglades Peat.

Treatment No.*	Phosphate Source	Precent P_2O_5 on Oven-Dry Basis			
		Turnips	Lettuce	Broccoli	Carrots
3	None	0.67	1.26	1.50	1.47
4	Superphosphate (18 per cent)	1.65	1.74	1.83	2.16
5	Superphosphate (44 per cent)	1.42	1.70	1.78	2.26
6	Rock phosphate	1.08	1.87	1.60	1.57
7	Basic slag	1.26	1.55	1.72	1.76
8	Colloidal phosphate	0.82	1.45	1.54	1.43

* From the same phosphate source experiment referred to in Table 1.

Table 4 shows the phosphorus content of some vegetable crops from these phosphate source plots. It may be seen that each of the sources of phosphate increased the phosphorus content of the vegetable to a considerable degree. In the case of turnips both sources of superphosphate gave the highest content of phosphorus. The lettuce obtained its phosphorus about equally well from all of the five sources. The phosphorus content of broccoli also was about the same irrespective of source of phosphate but the carrots, like the turnips, obtained a greater quantity from the superphosphates.

TABLE 5.—Effect of Source of Phosphorous on the Comparative Yield of Corn and Sorghum (Green Fodder Stage) Grown on Everglades Peat.

Treatment No.*	Phosphate Source	Comparative Yields	
		Corn	Sorghum
3	None	106	139
4	Superphosphate (18 per cent)	108	93
5	Superphosphate (44 per cent)	116	107
6	Rock phosphate	123	129
7	Basic slag	128	145
8	Colloidal phosphate	127	135

* From the same phosphate source experiment referred to in Table 1.

Crops of corn and sorghum, among numerous others, were also grown on these plots (Table 5). In general the best yields were obtained where the more insoluble phosphates were used, these being floats, basic slag and colloidal phosphate. Both corn and sorghum growing on the superphosphate plots (Treatments 4 and 5) were stunted as compared with growth on the other plots even including those where no phosphate was used. This adverse effect on the growth of corn and sorghum in the presence of soluble phosphate fertilizer has been observed at different times in these peat soils under field conditions as well as in other experiments. The reason for it is not entirely understood. Fertilizer experiments with corn in another series of plots are showing that corn needs considerable phosphate in fertilizer treatments but if too much is added, yields are reduced.

Sugarcane is another crop that is sensitive to the use of too much of the soluble superphosphate. Table 6 records the yields obtained from the phosphate source plots discussed above for other crops. Here it may be seen that cane yields were consistently higher where no phosphatic fertilizer was used except in the case of basic slag. The amount of sugar obtained per acre show these same relationships.

TABLE 6.—Effect of Source of Phosphorus on the Yield of Sugarcane Grown on Everglades Peat.*

Treatment No.**	Phosphate Source	Yield of Cane in Tons per A. (Year)			Pounds 96 Per Cent Sugar per Acre
		1931	1932	Avg.	
3	None	31.52	31.99	31.76	4,420
4	Superphosphate (18 per cent)	24.73	26.98	25.86	3,698
5	Superphosphate (44 per cent)	25.55	26.81	26.18	3,628
6	Rock phosphate	28.61	29.46	29.04	4,007
7	Basic slag	38.61	30.86	34.44	4,720
8	Colloidal phosphate	34.82	25.33	30.08	4,018

* Yield and sugar data furnished by F. D. Stevens, Sugarcane Agronomist, Everglades Station.

** From the same phosphate source experiment referred to in Table 1.

The phosphate content of sugarcane stem juices was determined in another series of plots all of which received potash and minor elements some with no phosphate and others with different phosphates at various

TABLE 7.—Effect of Source of Phosphorus and Rate of Treatment on the Phosphate Content of Juices of Sugarcane Grown on Everglades Peat.

Phosphate Source	Rate of Application (Lbs. per A.)*	P_2O_5 in Juice (p.p.m.)					
		Cane Variety Co. 281			Cane Variety P.O.J. 2714		
		Year		Average	Year		Average
		1932	1933		1932	1933	
No phosphate		606	333	470	407	289	348
Rock phosphate	500	639	353	496	385	375	380
	2,000	554	324	439	380	304	342
	3,000	780	536	658	550	413	482
Superphosphate (18 per cent)	250	720	462	591	585	411	498
	500	722	492	607	674	489	582
	1,000	1160	528	844	772	682	727
	2,000	1212	641	927	934	788	861
Basic slag	250	662	261	462	490	.....	
	500	615	280	448	482	268	375
	1,000	696	324	510	433	258	346
	2,000	728	383	556	500	305	403

* All plots in this series also received potash and secondary elements.

rates per acre (Table 7). An inspection of these data shows that the use of rock phosphate had little or no effect upon the phosphate content of the juices except where it was used at rates exceeding 2,000 pounds per acre. In contrast to this, acid phosphate increased the phosphorus content of the juices of both varieties of cane beginning with the lowest rate of application namely, 250 pounds per acre. Increasing the rate per acre to 500 pounds produced a marked increase in the phosphate content of the juices with still greater concentrations where applications were made at the rate of 1,000 and 2,000 pounds per acre. Basic slag was intermediate between rock phosphate and acid phosphate in its effect upon the amount of phosphorus taken up by the sugarcane. Growth of the cane was also somewhat better in the presence of basic slag.

Some of the conclusions which can be drawn from these experiments are that perennials such as sugarcane and grasses can utilize the less soluble forms of phosphorus sufficiently well if there is enough of the phosphate carrier present in the soil. On the other hand quick growing crops, such as the vegetables, require the soluble or acid phosphates for satisfactory growth in Everglades peat soils. This is especially true of the root crops such as turnips and carrots.

For best production of grain, corn and sorghum, phosphate fertilizer is required, preferably the acid or soluble forms. As in the case of sugarcane, however, too high an application will reduce yields.

PHOSPHORUS LEACHING STUDIES IN EVERGLADES PEAT UNDER LYSIMETER CONDITIONS

W. T. Forsee, Jr. and J. R. Neller [1]

Leaching studies were initiated in January 1940 on the lysimeters described at the 1941 meetings of the Soil Science Society of Florida (1). The data collected to date for phosphorus will be briefly discussed in this paper.

Experiments were started after the soil had been in place in the lysimeters for several weeks. Fertilizer applications were made on the basis of a 3-6-12 formula at 3,000 pounds per acre plus copper, manganese and zinc sulfates at 50, 50 and 10 pounds respectively per acre. The jars were then planted to celery. Leachates were measured periodically and a sample of 1/25 aliquot was saved. The composite leachate samples from each jar were preserved under toluene in tightly stoppered bottles prior to analysis. All samples of leachate and plant material collected for the period 1 1/40 to 7/2/40 were designated as Series I.

After this crop was harvested, the lysimeters were planted to cowpeas. This crop was turned into the soil at the end of the period designated as Series I. The next period, 7 2/40 to 2/20/41 is designated as Series II. During this time the jars were refertilized using the same rate and base formula as before, but omitting the trace elements. Due to the pronounced potash response of the celery in Series I, the check treatment, lysimeters No. 4 and 6, was changed to a complete fertilizer mixture (see Table 1). The lysimeters were then again planted to celery. Sample Series II terminated when this crop was harvested.

The lysimeters were then fertilized with the same base formula at the rate of 1,000 lbs. per acre. The trace elements were again included at the same rate as in Series I. Bountiful beans were planted. This crop was turned under and the soil remained fallow until the end of this period of leachate collections, Series III.

Cuttings of St. Augustine grass were then planted in the jars. The grass was clipped periodically and the individual samples composited for the period 10/23/41 to 10/26/42. The samples of this period were designated as Series IV.

The phosphorus recovered in crops and leachates during the four successive periods just described is recorded in Table 1. The loss of phosphorus by leaching was small for all periods. This loss is in most cases less than five per cent of the amount utilized by the crop and represents a very small proportion of the phosphorus added as fertilizer.

A summary, expressed in terms of pounds of phosphorus per acre, for the entire thirty-four month period of study is recorded in Table 2. For the soils that had received phosphorus fertilizer, the amounts lost by leaching were about six to eight pounds per acre. Soils receiving no phosphorus fertilizer showed a loss of about four and one-half pounds.

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TABLE I.—Phosphorus Recovered in Crops and Leachates from Lysimeters During Four Successive Leaching Periods.
(Given in Gms. P per Jar)

Jar No.	Treatment	Series I 1/1/40 to 7/2/40		Series II 7/2/40 to 2/20/41		Series III * 2/20/41 to 10/23/41	Series IV 10/23/41 to 10/26/42	
		Removed by Crop	Removed by Leaching	Removed by Crop	Removed by Leaching	Removed by Leaching	Removed by Crop	Removed by Leaching
4	NP2K **	0.132	0.012	0.625	0.045	0.029	1.624	0.051
6	NP2K	0.100	0.013	0.907	0.053	0.030	1.409	0.059
2	K	0.232	0.013	0.486	0.020	0.038	1.135	0.038
7	K	0.250	0.014	0.432	0.023	0.019	0.898	0 040
5	PK	0.365	0.024	0.752	0.041	0.030	2.143	0.070
9	PK	0.338	0.018	0.762	0.027	0.039	2.024	0 074
1	NPK	0.502	0.019	1.055	0.058	0.017	1.897	0 047
8	NPK	0.552	0.020	1.007	0.047	0.019	1.915	0.061
3	NPK + N †	0.636	0.025	0.958	0.037	0.028	1.367	0.097
10	NPK + N	0.610	0.039	1.112	0 034	0.022	1.449	0.076
Fertilizer application rate		3-6-12 at 3,000 lbs. per A.		3,000 lbs. per A.		1,000 lbs. per A.	none applied	
Gms. P added per jar		2.145 (4, 6, 2 & 7 none)		2.145 (2 & 7 none)		0.715 (2 & 7 none)	none	
Rainfall, inches		23.11		38.01		51.46	66.21	

* No crop was harvested during this period.

** For the period designated as Series I, no fertilizer was added to No. 4 & 6.

† This treatment included a side dressing of soluble nitrogen at intervals.

TABLE 2.—Summary for Entire Leaching Period 1/1/40 to 10/26/42.*

Lysimeter No.**	P. Added by Fertilizer Lbs. per A.	P. Removed (Lbs. per A.)		Percent of Added P. Removed		
		by Leaching	by Crops	by Leaching	by Crops	Total
4	126.0	6.04	104.9	4.79	83.3	88.1
6	126.0	6.83	106.4	5.42	84.4	89.8
2	none	4.80	81.6	.....	.....	.....
7	none	4.23	69.6	.....	.....	.....
5	220.5	7.27	143.6	3.30	65.1	68.4
9	220.5	6.96	137.6	3.16	62.4	65.6
1	220 5	6.21	152.1	2.82	69.0	71.8
8	220.5	6.48	153.0	2.94	69.4	72.3
3	220.5	8.23	130.4	3.73	59.1	62.8
10	220.5	7.53	139.7	3.42	63.4	66.8

* Rainfall for this period was 178.79 inches.

** For chemical treatment of the lysimeters see Table 1.

The soil water used in the sub-irrigation system contained a measurable quantity of phosphorus. Therefore, a portion of this phosphorus recorded as leaching was in fact added by the watering system. Thus, the amount of phosphorus actually leached was less than the amounts reported. A more accurate picture of the amount of added phosphorus leached would perhaps be the difference between the figures reported and the amount shown by lysimeters 2 and 7 which had received no phosphorus fertilizer. This would place the figures for added phosphorus leached at about 1.5 to 3.5 pounds. The phosphorus removed by the crops was very large, 59 to 84 per cent, in comparison to that removed by leaching. Thus, the phosphorus fertilizer added has been utilized very efficiently by the growing crops with little loss due to leaching.

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THE RELATIVE AVAILABILITY OF WASTE POND PHOSPHATE AS A SOURCE OF PHOSPHORUS AND CALCIUM FOR CLOVER [1]

G. M. Volk, G. C. Wilson and R. E. Blaser [2]

Waste pond phosphate is, as the name suggests, the deposit of finely divided material found in the old waste ponds associated with the hard rock phosphate mining operations in peninsular Florida. It is probably more commonly recognized by the name of "colloidal phosphate." The material is prepared for market by discing up the waste pond beds, allowing the material to air-dry and then grinding down to a finely granular condition. The granules are not cemented but readily slake down into a clay-like plastic mass when wetted.

A partial mineral analysis of a composite of the material made up from several sources is as follows:

P_2O_5	20.4%
Calcium	17.1
Zinc	.03-.08
Strontium	.03-.08
Barium	.01-.05
Vanadium	.008-.03
Chromium	.01-.05
Manganese	.01-.05
Cobalt	Less than .001
Zirconium	.08-.30
Nickel	.008-.03
Copper	.001-.005
Lead	.003-.008
Boron	.003-.008

In order to determine whether or not the phosphorus and calcium of waste pond phosphate is appreciably available to white Dutch clover, a series of greenhouse tests were conducted in two-gallon pots. One series was set up using Leon fine sand, a ground water podzol having a pH of 4.2. In a second series, another flatwoods soil, Plummer fine sand of pH 5.1 was used. Treatments were set up in triplicate. Fertilizer and lime were mixed with the surface four inches of soil in each pot and the clover immediately planted. The clover was clipped at intervals over a period of three months, oven dried and analyzed for yield and composition comparisons. Treatments and data on yield and composition are presented in Table 1. In addition to the treatment listed each pot received sulfate of potash at the rate of 100 pounds per acre on the basis of surface area. The yield from the best superphosphate treatment on each soil

[1] This work was made possible through the generous support of the Florida Agricultural Phosphate Association in the form of a research assistantship which was maintained in the College of Agriculture throughout the period of the study.

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TABLE 1.—Yield and Composition of White Dutch Clover Fertilized with Various Sources of Phosphorus and Calcium.

No.	Treatment Lbs./Acre			Soil Type: Leon Fine Sand				Soil Type: Plummer Fine Sand			
				Clover Analysis/D.W.		Soil	Yield	Clover Analysis		Soil	Yield
	Pond Phos.	Super-Phos.**	Lime †	Per Cent Calcium	Per Cent Phosphorus	pH	Rel. to No. 4	Per Cent Calcium	Per Cent Phosphorus	pH	Rel. to No. 5
1	0	0	2,000	1.66	.47	5.0	97	.....	..	6.0	13
2	0	600	0	.....	....	4.2	3	1.22	.28	4.7	84
3	0	600	1,000	1.55	.63	4.4	85	1.59	.37	5.5	90
4	0	600	2,000	2.10	.61	4.7	100*	1.69	.27	6.1	60
5	0	900	2,000	1.75	.63	4.8	87	1.70	.30	6.0	100*
6	0	1,200	2,000	1.88	.65	4.7	94	1.94	.30	5.8	96
7	1,500	0	0	.68	.77	4.2	35	1.14	.26	5.1	59
8	3,000	0	0	.71	.71	4.2	43	1.18	.29	5.2	69
9	6,000	0	0	.98	.75	4.2	46	1.47	.28	5.1	106
10	1,500	0	1,000	1.46	.56	4.5	92	1.43	.15	5.6	61
11	3,000	0	1,000	1.65	.62	4.4	94	1.55	.20	5.4	47
12	6,000	0	1,000	1.69	.63	4.5	92	1.61	.24	5.4	57
13	1,500	0	2,000	1.53	.51	4.8	94	1.84	.12	6.2	17
14	3,000	0	2,000	1.71	.55	4.9	104	1.84	.15	6.1	56
15	6,000	0	2,000	1.84	.50	4.9	103	1.80	.15	6.1	23

* Set at 100% for comparison. ** 18% superphosphate. † Precipitated chalk.

is set at 100 per cent and all other yields for that soil compared percentagely to it.

In general the treatments show that on the Leon soil there is a marked response to lime but little to phosphorus. On the Plummer soil the response is primarily to phosphorus.

Following the data on the Leon soils in order to study the response of clover to various sources of calcium, it is apparent from a comparison of treatments 7, 8, and 9 that the increasing increments of calcium supplied by the three levels of waste pond phosphate produce relatively small increments of increase in growth. The increased growth resulting from increasing the application of waste pond phosphate from 1,500 pounds to 6,000 pounds is only 31 per cent while the increase resulting from the addition of 1,000 pounds of lime to the 1,500 pound application of waste pond phosphate is 163 per cent. On this basis, the relative effectiveness of lime as compared to waste pond phosphate as a source of calcium is approximately 20:1 on the weight basis. This is further reflected in the calcium content of the clover which increases 44 per cent from the 4,500 pound increment of waste pond phosphate as compared to 149 per cent for the 1,000 pounds of lime. It is interesting to note the reduction in phosphorus content in the palnts as the lime application increases. This is probably the result of reduction in luxury consumption of calcium as growth increases but may be the depressing effect of lime on intake of phosphorus.

The comparison of availability of phosphorus is best made on the Plummer soil. A comparison of treatments 7, 8, and 9 show that there is an increase in yield as increments of waste pond phosphate are added. This is reflected to some extent in the phosphorus content of the clover. There is also a consistent increase in calcium content where no lime is applied. However, this is probably a secondary effect of the increase in phosphorus intake. There is a marked depressing effect of lime on the intake of phosphorus from waste pond phosphate as seen by comparing treatments 7, 10, 13 or 8, 11, 14 or 9, 12, 15. The calcium content increases from 1.14 per cent to 1.84 per cent with the addition of a ton of lime to the 1,500 pound waste pond phosphate treatment while the phosphorus decreases from .26 per cent to .12 per cent.

From the preceding it appears that the calcium of waste pond phosphate is relatively slowly available as compared to that of lime. The phosphorus it carries is appreciably soluble in acid soils but considerable crop response information must be accumulated to determine the degree and significance of this solubility.

In order to study further the nature of the solubility of calcium and phosphorus in raw phosphates, a series of comparisons between waste pond phosphate and raw rock phosphate in terms of percentage comparison to the yield of recommended superphosphate treatments was compiled from existing data. The superphosphate treatment was at the rate of 600 pounds per acre in a mixture containing a ton of lime and 100 pounds of muriate of potash. Refertilization was usually at the rate of one-fourth to one-half this rate of superphosphate and potash the second year. The potash rate always equaled that used with the raw phosphates in any comparison.

TABLE 2.—Relative Yield from Ground Rock Phosphate and Waste Pond Phosphate Treatments as Compared to Reference Superphosphate Treatment.*

No.	Treatment				Yield Relative to Reference Treatment	
	Raw Phosphate ** Pounds per Acre	Superphosphate Pounds per Acre	Muriate of Potash Pounds per Acre	Lime Pounds per Acre	G. Rock P. First Year Response	W. Pond P. First Year Response
1	3,000		100		100%	82%
2	3,000		100	500	70	68
3	1,000		100	2,000	56	65
4	3,000		100	2,000	96	76
5	3,000	200	100	500	67	65

No.	1st Year — 2nd Year	1st Year — 2nd Year	1st Year 2nd Year	1st Year 2nd Year	Second Year Response	
7	3,000 — 0		100 — 50		53	80
8	4,500 — 0		100 — 50		78	72
9	6,000 — 0		100 — 50		63	59
10	3,000 — 0		100 — 50	0 — 2,000	66	80
11	4,500 — 0		100 — 50	0 — 2,000	74	82
12	6,000 — 0		100 — 50	0 — 2,000	69	74
13	3,000 — 0		100 — 50	500 — 0	78	53
14	3,000 — 0		100 — 50	500 — 500	79	53
15	3,000 — 0		100 — 50	2,000 — 0	80	68
16	3,000 — 0		100 — 50	2,000 — 2,000	67	66
17	3,000 — 0	200 — 0	100 — 50	500 — 500	74	64
18	3,000 — 0	200 — 0	100 — 50	0 — 1,000	63	60
19	3,000 — 0	200 — 0	100 — 50	0 — 2,000	55	61
20	3,000 — 1,500		100 — 50		66	48
21	3,000 — 750		100 — 25	2,000 — 0	52	67
22	3,000 — 0	200 — 200	100 — 50	500 — 500	73	91
Average					67%	65%

* 600 lbs. superphosphate, 100 lbs. muriate of potash, and 2,000 lbs. lime, refertilized by ¼ to ½ these quantities the second year.
** Florida ground rock phosphate 52% passing 200 mesh sieve, 32% P_2O_5 content.

Table 2 lists the treatments and percentage comparisons to the yield from the reference superphosphate treatment. This data is selected from several test areas on acid flatwoods soils. Clover on all areas responded to phosphate applications and only those raw phosphate treatments producing at least 50 per cent of the yield of the reference superphosphate treatment are listed.

Study of the data in Table 2 shows that there is no consistent difference in response to the two types of raw phosphate. The type of ground rock used must be taken into consideration. However, the fact that heavy applications do not consistently give yields higher than lighter applications suggests that the upper limit of availability under the existing conditions of the test has been reached. From this data it appears that waste pond phosphate is very similar to ground rock phosphate. The buffer capacity and fixing power of the soil probably largely dominates any inherent differences in the materials.

The yields relative to the reference superphosphate treatment are not a reliable measure of the true value of raw phosphates because no measure of their ability to supply phosphorus or calcium over a long period of time is made. It is conceivable that while they do not support the same maximum growth as does superphosphate, they will over a period of time offset this by maintained yields and an ultimate lower cost per unit of forage produced. Such can only be determined by long time trials which are now in progress. If the increased cost of obtaining maximum yields in clover can be justified, then it is doubtful if raw phosphates can be recommended as a sole source of phosphorus. Combinations of superphosphate and raw phosphates show promise as economical clover establishment mixtures.

There are certain soil characteristics which must be kept in mind when evaluating raw phosphates. Soils with a high phosphorus fixing capacity or soils at or above neutral will interfere with the availability of the phosphorus. High fixing soils severely compete with the plant for any phosphorus brought into solution, while alkaline soils will prevent solubility of raw phosphates to a marked degree. Raw phosphates have the best opportunity of satisfying the phosphorus needs of perennial or long season crops growing on acid soils low in sesquioxides.

THE OUTLOOK FOR INSOLUBLE SOURCES OF TRACE ELEMENTS UNDER FLORIDA CONDITIONS

R. V. Allison [1]

The few words for which time can be found to discuss natural sources of the so-called trace elements in such a lengthy soil fertility symposium as has been held this afternoon could doubtless best be used in showing the closely parallel position they and their refined derivatives occupy with relation to rock phosphate and superphosphate of which we have heard so much in more than half of the papers that have been presented.

Although studies with rock and colloidal phosphate, as comparatively insoluble sources of prosphorus, and with feldspar, as a natural source of potash, have been under way for a number of years little has been done, as yet, with generally similar sources of some of the more important trace or minor elements that are finding a more and more vital place in our soil fertility program here in Florida and elsewhere in the Southeast.

The principal question to be answered is, of course, for what crops and on what soils, if any, can such natural ores of any of these elements, as may be available in commercial quantities serve, when finely ground and applied in a proper manner and at a proper rate, as an economical source of these metals for plant growth.

The parallel nature of the question with that of rock phosphate and superphosphate lies in the fact that the unit cost of the element sought is usually several times greater in the manufactured than in the natural form. This, of course, is readily understood due to the expensive chemical treatments and considerable handling that, of necessity, are involved in the transformation of these elements from crude ores to comparatively refined and readily soluble forms. The above question thus contains the very definite challenge as to what conditions, both as to soils and crops, will permit the use of these natural ores as sources of copper, manganese, zinc, boron and/or cobalt with a consequent saving in cost due to the fact that the requisite solubilization processes are going on in the soil body itself, rather than in the factory, as a result of natural action by soil microorganisms, moisture, temperature and the various organic acids of the soil and plant roots with which such materials must come in contact in such an environment. Other potential advantages that might be mentioned in favor of the natural product are prolonged availability and protection against leaching as well as damaging residues that might develop from the continued use of highly soluble salts of any or all of these metals under certain conditions.

That insoluble sources of trace elements are satisfactory for plants when applied to certain soils in the right amount is indicated by the fact that some growers have gotten quite satisfactory results with the use of zinc oxide on citrus. Some time ago, too, in the early manganese studies

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on Everglades peat, the writer obtained quite a definite response to manganese carbonate when applied to beans even on a highly calcarious soil where the pH had been increased to 7.0 or higher by earlier burning.

Likewise the inclusion of an insoluble source of boron in a complex mineral mixture made available for research some time ago has been found a satisfactory source of this element for cabbage on an Arrendonda fine sandy loam; also for clover on a mixed soil area involving Immokalee, Plummer and Leon fine sands.

Just as in the case of superphosphate, the question is not one of doing away with the refined product. This will never be possible in any sense of the word, especially for rapidly growing crops under certain soil conditions. However, there are cropping systems in Florida, large scale operations in some instances, such as range pasture conditions, where if only a few pennies can be saved per acre on fertilizer sources it may mean the difference between success and failure in the future.

It is particularly with those growers who find themselves in these narrow economic ranges of operation and management in mind that this question of economy in the use of insoluble sources of trace elements is first raised; and it should not be forgotten that once the current high prices due to the impact of wartime demands passes there may be an ever-increasing need, even a critical need, for this type of information. This being the case it is our present hope that this field of research be pressed rather than neglected in order that at least a reasonable amount of specific data may be available when needed. It is in studies of this nature that a fully coordinated system of soil and plant testing will find a really useful field of application.

SYMPOSIUM: NEMATODE CONTROL UNDER FLORIDA CONDITIONS

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College of Agriculture, University of Florida
Saturday, December 19, 1942

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INTRODUCTION

Dr. H. H. Hume, *Chairman*

The meeting was called to order by Dean H. H. Hume, College of Agriculture, at 9:30 A.M. In his introductory remarks, Dean Hume spoke particularly of the extent and economic significance of the nematode problem in Florida and elsewhere as being one of the most serious to be found anywhere in the South.

The problem, he said, seems to be largely one of learning to live with the nematode especially through the development of plants that are tolerant or resistant, if not actually immune. In pointing to the fact that research must be organized on a very broad basis in the future if we are to get very far in the solution of such a complex problem, reference was made to the quite serious efforts at a comprehensive coordination of investigations in this field on a regional basis that have been made in the past but which largely have come to nought.

Dean Hume's remarks closed in a somewhat optimistic vein, however, based on the unusual results currently being obtained through the use of certain chemicals which might well prove the basis for a quickened interest in the whole problem in contrast with the rather frightening indifference of the past.

PLANT NEMATODES THE GROWER SHOULD KNOW

G. Steiner [1]

PART I [2]

In yesterday evening's address [3] an attempt was made to present to you a general picture of the significance of nematodes as part of the biological component of the soil. During today's presentation. in accordance with your request, I shall try to give a review of nematode forms and types that are considered of importance to the grower because of a direct or indirect relationship to crop production.

For some decades nematologists have emphasized the presence of enormous numbers of nematodes in our crop lands and have singled out many species which are plant parasites or plant pathogens and therefore of significance to plant growth and crop production. But only during recent years has an increasing realization of the economic significance of plant nematodes as pests of crops, and as limiting factors in crop production been developed by growers and research workers. That this disregard of nematodes as a factor in soil response has had its serious consequences in research, particularly in soil science. may be illustrated by the fact that various extensive fertilizer tests made in Florida have had to be repeated because of their insidious damage. It is obvious that test crops having diseased and parasitized root systems will not respond in the same manner as would those with normal and healthy roots. The soil scientist should therefore be aware of the modifying effect nematodes may have on the results of his studies with fertilizers, cover crops, trace elements, etc.

For years the opinion was prevalent that there was just one significant nemic plant pest, the root-knot nematode, and it was spoken of as "the nematode." Although this root-knot nematode is recognized the world over as one of the worst and most perplexing agricultural pests it is certainly not the only significant one. There are many other important plant nematodes such as the meadow nematodes (a group of forms belonging to the genus *Pratylenchus* Filipjev), the spiral nematodes (Genus *Helicotylenchus* Steiner),[4] the kidney-shaped nematode (Genus *Rotylenchulus* Linford), the lance nematodes (Genus *Hoplolaimus* v. Daday), the puncturing nematodes (Genus *Dolichodorus* Cobb), the stylet nematodes (Genus *Tylenchorhynchus* Cobb), the ring nematodes (Subfamily Criconematinae Chitwood), the pin nematodes (Genus *Paratylenchus* Micoletzky), the seed gall nematodes (Genus *Anguina* Scopoli), to which

[1] Principal Nematologist, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture.

[2] Part II, dealing with nematodes affecting the aerial parts of plants is in process of preparation.

[3] Nematodes and the life association of the soil, p. 7, this volume.

[4] *Steiner, G.*, 1945: Helicotylenchus, a new genus of plant-parasitic nematodes and its relationship to *Rotylenchus* Filipjev. Proc. Helminthological Soc. Washington. Vol. 12, 34-38, fig. 1A-F.

belongs, e.g., the wheat nematode (*A. tritici* [Steinbuch] Filipjev), the bulb and stem nematodes (Genus *Ditylenchus* Filipjev), which represent a group of different species including, e.g., also the rice nematode (*Ditylenchus angustus* [Butler] Filipjev), the potato rot nematode (*Ditylenchus destructor* Thorne), the sugar-beet nematode (*Heterodera schachtii* Schmidt), the golden nematode of potatoes (*H. rostochiensis* Wollenweber), the citrus nematode (Genus *Tylenchulus* Cobb), the bud and leaf nematodes (certain species of *Aphelenchoides* Fischer, such as the fern nematode, *A. olesistus* Ritzema Bos; the cocopalm nematode, *A. cocophilus* Cobb; the strawberry nematode, *A. fragariae* Ritzema Bos, causing spring dwarf in strawberry plants; Bessey's strawberry nematode, *A. besseyi* Christie, causing summer dwarf; the chrysanthemum nematode, *A. ritzema-bosi*), the needle nematodes (Genus *Xiphinema* Cobb), and certain spear nematodes of the Genera *Dorylaimus* Bastian, *Pungentus* Thorne and others. There are known today several hundred different species of nematodes that attack plants and at least a dozen must be considered major pests while others will undoubtedly be considered as such after they are better known. In general, however, their significance as pests is certainly underestimated. There are several reasons for this. One is the soil-borne character of all plant nematodes; a second, their small microscopic size; a third, their hidden mode of life either in the soil or inside the plant tissues; a fourth, that their study is technically very difficult; a fifth, that they are considered a border subject not properly belonging to the field of the entomologist or that of the plant pathologist or the parasitologist. In addition plant nematology and its related subject—soil, freshwater, and marine nematology—are not given as courses in our colleges and universities and are considered only a side line of research by most agricultural institutions.

Then, too, there is the tendency on the part of growers and investigators to judge the health and growth conditions of plants mainly on the basis of the appearance of the above-ground parts. This generally leads to an underestimation of the significance of nematodes in their role as plant pathogens and their influence on plant growth. Since the roots and other underground parts of plants are the principal portions attacked by nematodes, a full evaluation of their damage naturally necessitates the uprooting of a sufficient number of plants for inspection of the root system. This, of course, often means the loss of many plants. In the case of shrubs and trees this may involve a considerable loss without the gain of more than a chance result. The evaluation of the significance of other underground pests and diseases of crops, as in the case of plant nematodes, is also more difficult than that of those found above ground.

Growers frequently are also inclined to blame reduced yields on a lack of soil fertility, on deficiencies of certain elements, on drought and other seasonal conditions, on winter kill, sunburn, lightning, and other factors, when actually nematodes may be the cause of these conditions. Growers also sometimes tell of the wonderful crops they or their parents used to grow and that the production of such crops is no longer possible, even with heavy applications of fertilizers. We are convinced that many

such instances not infrequently would prove upon examination to be the result of root destruction by nematodes. In other countries the term "sick soil" is sometimes used to express failure of a given soil to continue to produce, notwithstanding fertilizer applications or the use of other means to induce increased production. Nematodes were repeatedly found to cause such conditions, often more specifically termed by growers as "alfalfa sick soil," "clover sick soil", "soil tired of beets", "tired of potatoes", etc.

It is agreed that with our monoculture, that is a single identical crop planted over wide areas not infrequently year after year or at least, in close succession, pests and diseases of such crops are provided with favorable conditions for development. They therefore increase tremendously, particularly in the absence of any natural checks. But here again in our attempts to look for and control pests and diseases, the above-ground parts of our crops have attracted most of our attention and consumed most of our efforts. This has led to modern pest control of these aerial parts by spraying and dusting practices and by fumigation. A great deal of research work has been and still is being done in this connection. However, the root systems and other underground parts of plants have not gotten their share of attention although soil-borne pests and diseases, particularly our plant nematodes, are equally favored by our monocultures.

Fortunately plant nematodes are slow in their spread and are usually not of such a lethal virulence as many of the fungous, bacterial, and virous diseases. An outright killing may be effected on seedlings but this is rather an exception on fully grown plants. Nematode diseases cause a reduction in growth and vitality, but generally are not completely lethal. Thus it would appear that, in general, the host-parasite relationship between plants and nematodes is a highly balanced one, that is, the parasite does not at once kill the host and so deprive itself of a means of existence. This situation has made these pests appear less impressive and thus has been another reason for the under-estimation of their importance.

It is also a fact that many of these pathogenic nematodes, more or less unconsciously, have been kept under control to some degree by certain agricultural practices. Plowing, discing, harrowing, and cultivation are some of the operations that help and are not to be under-estimated as a means of reducing noxious nematodes in the soil. This is accomplished by exposing the nematodes to the sun, to drying by wind, to starvation by depriving them of a living host, to mechanical injury, etc. Crop rotation also has long been recognized as an extremely helpful agricultural practice through the tendency to reduce the nematode population by starvation providing, of course, that one or more crops used in the rotations are not a host of the particular nematode or nematodes present in a given soil. Thus various agricultural practices, to some extent, have been effecting a certain amount of control over soil-borne nematode pests of plants, but also have assisted in delaying a proper appraisal of their importance.

This situation began to change with the coming of soil sterilization by steam and other means including the use of efficacious soil fumigants.

The efficient control of root-parasitic nematodes and other biotic factors antagonistic to plant growth through these methods usually results in remarkable increases in plant growth: the higher yields thus proving quite conclusively the really detrimental effect of nematodes on crop production. But here again, past and current conceptions have been slow to acknowledge the beneficial effects as being mainly the result of parasite and disease control.

That the sterilization of soil by steam makes for better growth of plants, frequently to such an extent that fertilizer applications may be omitted, has long been known. For an explanation of this phenomenon it was assumed, however, that such sterilization made more nitrogen available and that this condition rather than parasite and disease control, was responsible for the growth and yield increase. With the advent of efficacious soil fumigants such as carbon bisulphide (CS_2), chloropicrin ($C\ Cl_3NO_2$), methyl bromide (CH_3Br) and others, including the most recent DD mixture (1,3 Dichloro-propylene—[CHCl=CH-CH_2Cl] Dichloropropane—[CH_2Cl-CHCl-CH_3]), the same explanation was still promulgated. Here too, an increase of available nitrogen was assumed and thought to cause growth "stimulation." Peculiarly enough the question of where this nitrogen originated, particularly with fumigants not containing it, did not arise. It was argued that both steam and chemical sterilization will kill most, if not all organisms in the soil, and thus make more nitrogen available through the decomposition of the bodies of these organisms. Such an argument appears fallacious. If it were correct, then man too would have his living space affected only through decomposition of his body after death. Life is action and it is the *living* biological factor in the soil that exerts the more extended, the more intensive, and the more significant action on plant growth rather than the dead one. That is to say it is the living plant-parasitic and plant-pathogenic biotic factors in a given soil which are responsible for reducing the growth and production of crops growing therein. We are convinced that the striking increases in growth and yield that frequently follow sterilization, either by steam, hot water, or fumigants, are largely the result of parasite and disease control and, more particularly, nematode control. The results of soil fumigation in our opinion thus emphasize the very great importance of plant-parasitic nematodes in crop production.

Thus the growing recognition of the significance of plant and soil nematodes as a factor in crop production is well founded. It is hoped that it will lead to helpful developments for the control of these crop-antagonistic biotic factors through the use of more efficacious fumigants, and better methods of application. Here the way is open for significant increases in crop production combined with a possible reduction of acreage and a lessor need for fertilizers. Let us provide healthy root systems for our crop plants through control of the many nematodes and other agents now causing root lesions, root decay, root amputations, blind root tips, abnormal matted growth, etc., and surprising yield increases will result. A healthy root system will more effectively utilize a lower fertility level in a soil or take more advantage of one that has been

artificially increased by fertilizer applications, than will one that is affected by disease.

Figure 1.—Roots of a tobacco plant grown in South Carolina and disfigured through a heavy infection by the root-knot nematode. Note the stunted, blinded and swollen roots and compare with type of root disfiguration and galling shown in Figure 2. Such variations in character of root galling and disfiguration may be related to different root-knot nematode strains or races, but may also be the result of different reactions by the hosts.[1]

How are the growers to recognize the presence of these microscopic nematode pests on their crops, and how are they to know the kinds involved? Are there specific symptoms which indicate that a disease or abnormal behavior is caused by a nematode, or an association of nematodes, or a combination of nematodes and fungi or bacteria, or a combination of all three of them, or a combination of still some other factor or group of factors with nematodes? Unfortunately there exists only one sure way to determine this, namely the location and identification of the nematodes themselves. May we therefore emphasize that it is not possible to recognize and properly diagnose nematode diseases of plants

[1] Most of the photographs used to illustrate the present paper were taken by Mr. Marcel L. F. Faubert of the office of Plant and Operations; others by Mr. Wilfred T. Mead of the Bureau of Plant Industry, Soils and Agricultural Engineering. The author wishes to express to both of them his appreciation for the excellent service.

by symptoms alone: in every instance the nematode itself should be located and determined before a final diagnosis is made. Let us support this statement by an example. It is widely assumed that the root-knot nematode may be correctly recognized and properly diagnosed through the symptoms it causes on the roots of its host plants, namely conspicuous swellings, knots or galls. (Figs. 1-3) But even in this instance it is fallacious; such symptoms are only indicative but certainly not proof of an infection by the root-knot nematode because: (1) there are knot-forming nematodes found on roots of plants other than the root-knot nematode (e.g. *Ditylenchus radicicola* [Greeff] Filipjev, or *Nacobbus dorsalis* Thorne & Allen). (2) the root-knot nematode may be present without causing the formation of knots (this is often seen, e.g., in cotton or corn where the nematode breaks through the surface of a root without forming knots) and roots are then mistakenly judged free, (3) other organisms may form similar knots, e.g. the slime molds (*Plasmodiophora* species) causing clubroots in members of the cabbage family, the crown gall organism (*Bacterium tumefaciens* Sm. & Town) and certain viruses;

Figure 2.—Roots and pods of a peanut plant (*Arachis hypogaea* L.) infected with the root-knot nematode which formed only small galls on the roots but blackish lesions on the pods. This attack at the ends of pods causes interruption of growth and misshapen and often dwarfed pods.

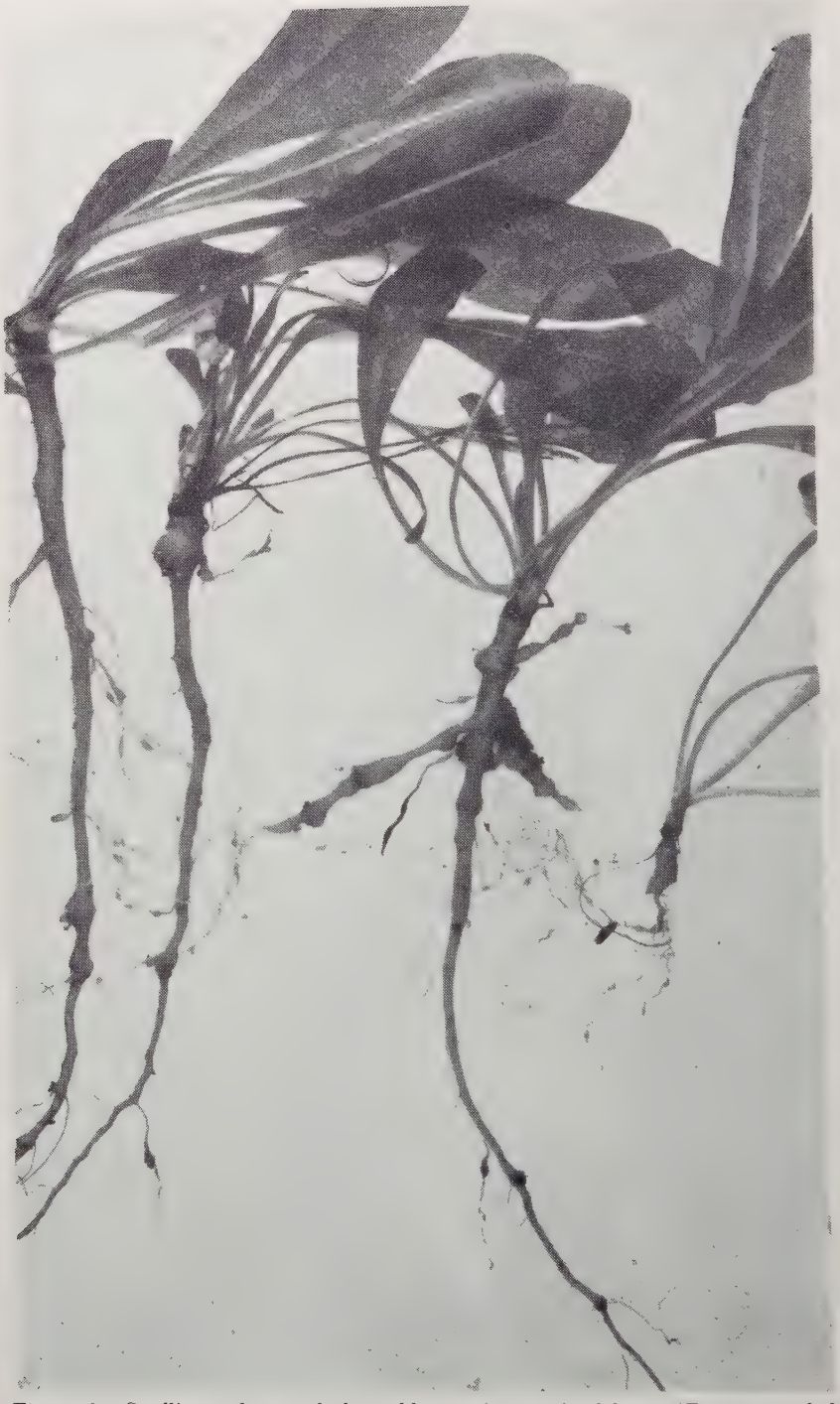

Figure 3.—Seedlings of one of the rubber-producing dandelions (*Taraxacum koksaghyz* Rod.) exhibiting root swellings caused by the root-knot nematode.

Figure 4.—*A.* Heavily knotted and crippled roots of a Laredo soybean plant grown in Virginia infected with the root-knot nematode; ⅔ normal size. *B.* Heavily knotted and crippled roots of a young *Castilla elastica* Cerv.; ⅔ normal size.

Figure 5.—*A.* Roots of black locust seedlings (*Robinia pseudoacacia* L.) damaged by the root-knot nematode. Note the swollen and blinded root tips; ¾ normal size. *B.* Roots of a daylily (Hemerocallis hybrid) infected with the root-knot nematode. Note again the blinded root tips; otherwise the knots and galls are only slightly noticeable on the fleshy roots; ¾ normal size

also so-called bacterial nodules may be mistaken for root-knot galls, but they usually are easily distinguished from knots caused by the root-knot nematode by the fact that they are mostly fixed on a short peduncle and hang on the side of a root whereas the swelling caused by the root-knot nematode is most often an axial one of the root proper (Fig. 9), (4) there are certain plants that have normally knotted or swollen roots (e.g. *Parthenocissus* sp.). Thus it is evident that even this common root-knot nematode disease must be diagnosed by the presence of the organism itself rather than through the occurrence of knots of one kind or another on the roots.

Figure 6. *A.* Root-knot infected sweetpotatoes; the sweetpotato to the left exhibits cracking which appears to result in certain instances from a root-knot infection. *B.* Beet heavily infected and disfigured by the root-knot nematode. *C.* Carrot disfigured and made unmarketable by the root-knot nematode; ½ normal size.

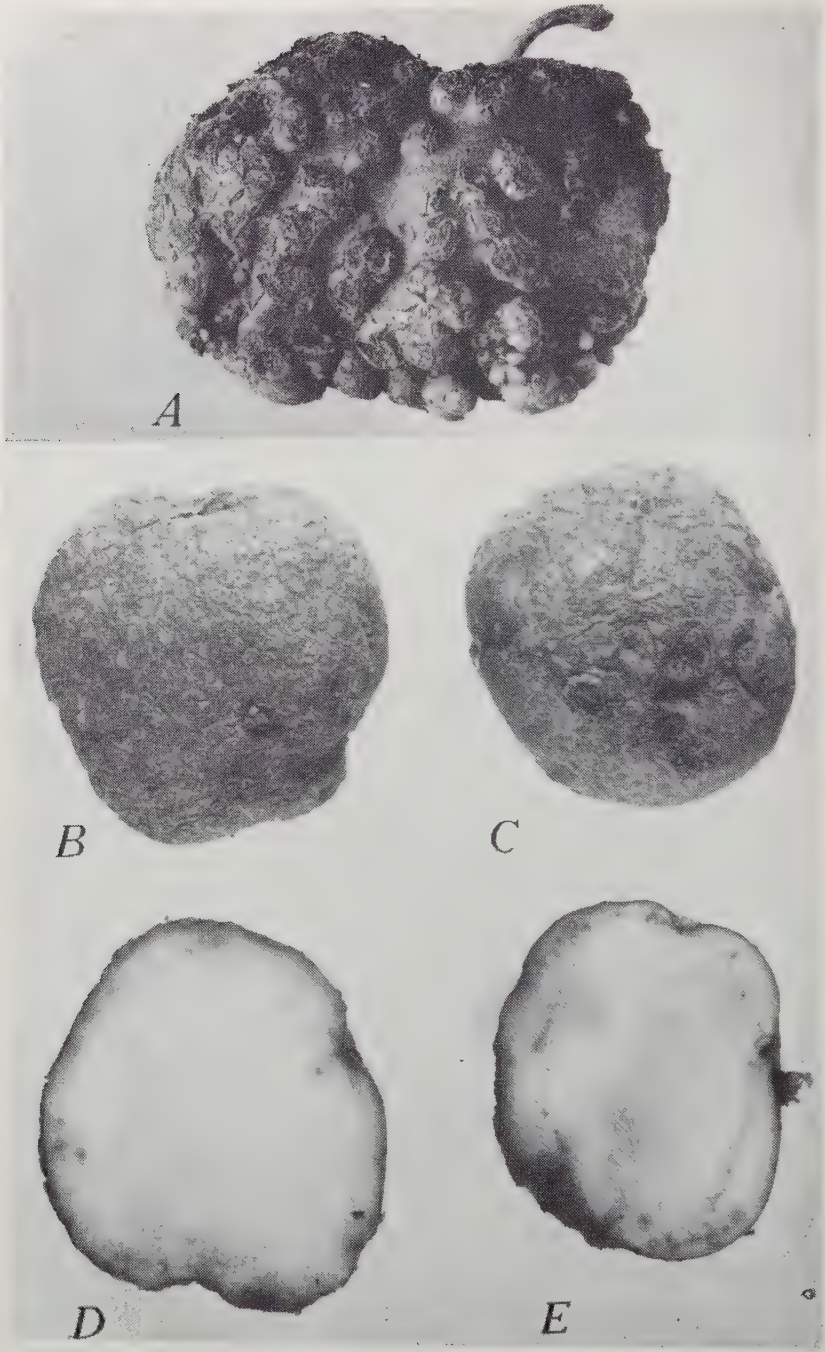

Figure 7.—*A*. Bliss triumph potato badly infected and disfigured by the root-knot nematode. Specimens collected at Gainesville, Florida. Note the protruding knobs formed by the nematode and compare with *B* where symptoms are sunken, crater-like spots. *B-E*. Bliss triumph potato infected and disfigured by the root-knot nematode. Specimens collected at Tampa, Florida. It is thought that the difference in symptoms observed in the potatoes of *A* and *B-E* of this Figure are the result of racial differences in the attacking nematode populations; ⅔ normal size.

Furthermore, for a proper assay of the status of a given plant as a host, it should be ascertained whether the nematode is actually producing progeny on it. For a demonstration of this point the root-knot nematode may serve again. Our observations appear to show that the pre-parasitic larvae of this form enter the roots or subterraneous stem and leaf formations of almost any type of plant in spite of the fact that, in most

Figure 8.—*A.* Root-knot infected bean seedling with galls also on the leaves (at arrow). *B.* Root-knot infected bean seedling with galls also on the stem (at arrow). *C & D.* Malformed and dying bean seedlings with heavy infection of the root-knot nematode; ½ normal size. Attention may be called to the fact that such heavy invasions of seedlings, leading to the ultimate death of the plants before the invading nematodes have time to produce progeny, may lead to such a reduction in the number of nematodes that a replanting with beans may be fully successful.

cases, they are unable to develop in them and to produce progeny. In 1937 it was found that the root tips of French marigolds (Tagetes hybrids) were heavily invaded by larval root-knot nematodes, while galls with fullgrown females producing egg masses were observed in only small numbers. Upon closer study it was shown that most of the larval nematodes that invaded these roots were unable to develop to the adult stage and died before reaching it. Obviously these resistant marigolds did not furnish the invading root-knot larvae with the proper food, or the nema-

tode larvae did not have the ability to induce the invaded host to produce their food. Further studies on so-called resistant plants showed a similar situation to exist, e.g. in *Crotalaria spectabilis* Roth, *Solanum grandiflorum* R. & P., lantana (*Lantana camara* L.), "dusty miller" or silver cineraria (*Senecio cineraria* DC.), *Nicotiana megalosiphon* Huerck & Muell. Arg. and *Nicotiana plumbaginifolia* Viv. *Crotalaria spectabilis* proved to be

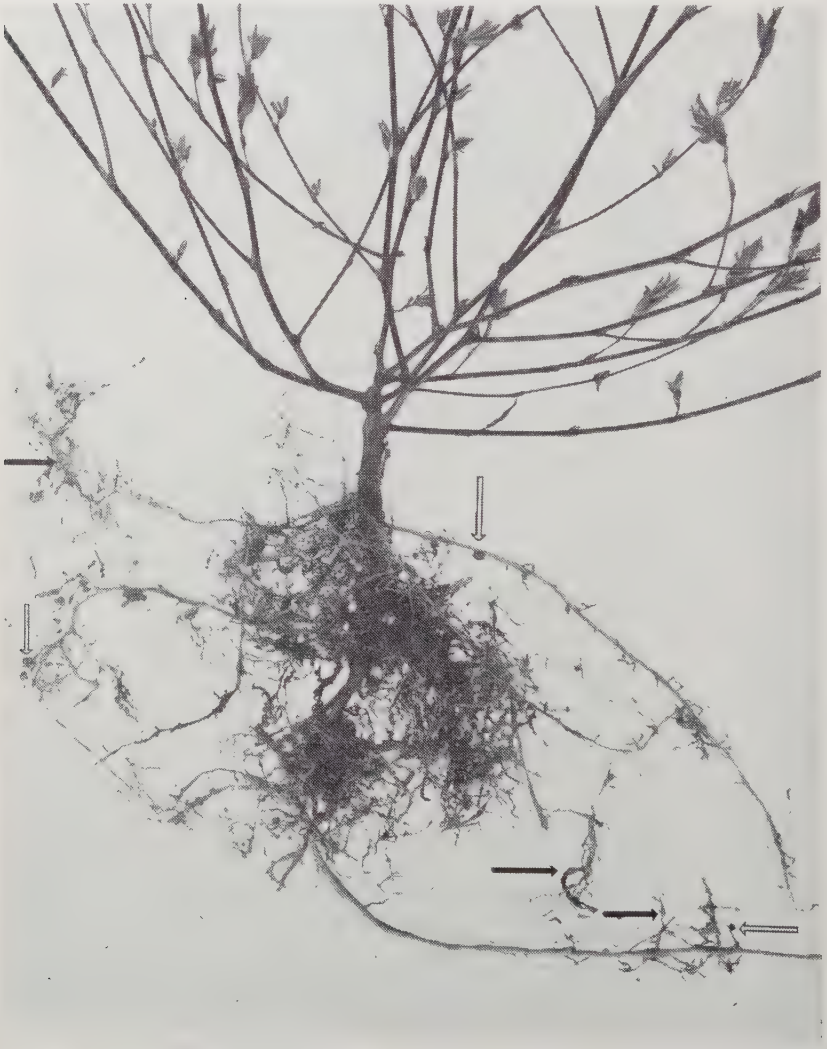

Figure 9.—*Lespedeza stipulacea* Maxim., Korean clover, showing nodules caused by the root-knot nematode (solid arrows), and nodules caused by beneficial nitrogen-fixing bacteria (open arrows). Coll: Virginia, 1941; ⅔ normal size. It may be mentioned that this lespedeza is an excellent indicator plant to detect the presence of the root-knot nematode in the soil. Where this nematode occurs in a soil growing this species, the plants always will be stunted and yellow.

one of the most interesting plants yet studied in its host-parasite relationship with the root-knot nematode. It was observed that the root tips of growing specimens are invaded by large numbers of larval root-knot nematodes, but up to the present time not one larva has ever been found to have reached the adult stage. They all appear to perish at a very early stage of fixation in the root. This legume is therefore an excellent trap plant and cover crop combined. On the basis of greenhouse and field experiments it has been found very effective in cleaning infested land of the root-knot nematode. In entering the roots the nematode appears to be able to induce the root tissues to produce the so-called giant or nectarial cells on which it feeds, but for some reason the nematode will not grow to the adult stage and produce eggs and progeny. However, even in this case the plant suffers from an invasion of its roots by these nematode larvae: this is shown by the fact that small seedlings of *C. spectabilis* will die or at least appear sick for a time after invasion. Eventually the plant will recover. *Solanum grandiflorum* R. & P., a weed growing in Brazil [5] and used there as a root stock for tomato grafts on root-knot-infested lands, exhibits characteristics quite similar to those of *Crotalaria spectabilis* in its relationship to the root-knot nematode. Here, too, the roots are invaded and their tips blinded by the larval root-knot nematode which again is unable to grow and develop as it becomes fixed. This Solanum eventually will also attract from the soil larval specimens of the nematode but will recover after their invasion and death. Here again the young seedlings may suffer badly from this invasion and, in fact, may even be killed. Of a total of 100 seeds planted in root-knot-infested soil only three seedlings survived while a control planting from the same lot of seed in sterilized soil gave full germination and only healthy growth.

Still another variation in host-parasite relationship is shown by the rose geranium (*Pelargonium graveolens* [Thumb] L'Hérit). In this plant the roots also appear to possess considerable resistance against attack. Few galls are formed, many of which are empty, and only occasional ones were observed with egg-laying females. In contrast to this behavior of the roots, the basal portion of the stem appears to be very attractive to the root-knot nematode and consequently is invaded by large numbers, galls being formed and female specimens being able to grow to maturity and produce eggs (Fig. 10).

We are convinced that a study of the numerous host plants affected by the root-knot nematode, including the so-called resistant and immune types, will bring to light additional information of much value for a better understanding of these numerous and complex host-parasite interrelationship. These are all matters of not only theoretical interest, but of great practical importance since they find their application in control through effective crop rotations.

There are still other complicating factors that make the diagnosis of root-knot infections and a proper appreciation of their significance difficult. Observations on the host range of this nematode in different regions and locations, as well as studies on the resistance of an identical crop

[5] For the opportunity of studying this plant we are indebted to S. B. Fenne of the Institute of Inter-American Affairs.

Figure 10.—Roots and basal stem of a rose geranium exhibiting galls (at arrows) of the root-knot nematode.

variety planted at different locations, have shown that plants and crops attacked in one location sometimes are not attacked in another. Evidence is rapidly developing through systematic studies to prove that there exist different host strains or host races of this nematode, each of which has its own host range; some regions or localities appear to have only a single strain, whereas in others two or more occur, often in a mixed state. A similar situation appears to exist in other nematode species, for example, the bulb and stem nematode or certain bud and leaf nematodes (Aphelenchidae species). These matters are mentioned to emphasize the fact that the diagnosis of a nematode infection and the evaluation of its capacity for damage must be made with care and knowledge.

Disease symptoms produced by the various species are rarely specific; wilting, discoloration of leaves, swollen and distorted shoots, crinkled leaves, leaf spots, gall formation on roots, stems and leaves, galled fruits and seeds, bunching and dwarfing of the entire plant, blinding of buds, and the phenomena termed dieback, sunburn, winter kill and winter bronzing may be caused by nematodes. General wilting of plants in the field over a hot period of the day may be indicative of the presence of large numbers of root nematodes, as may also bare spots or areas exhibiting retarded or reduced growth. However, all of these symptoms likewise may be caused by various other organisms and agents. Again, therefore, external symptoms alone can not serve as a reliable basis for the diagnosis of a nemic plant disease. The identification of the organism is absolutely necessary.

Nematodes, or eelworms, so far as plant-parasitic forms are concerned, are very small animals, less than 2 mm long, usually only from 0.4 to 1 mm (or 1/64 to 1/25 of an inch). Therefore they can not be seen with the naked eye and must be studied with the microscope. Although of such small size, their organization is highly complex and embraces all organs and organ-systems found in higher animals except a circulatory system. It is difficult for the untrained worker to differentiate the various genera and species and some of the thousands of soil-inhabiting forms may easily be mistaken for those which are definitely parasitic to plants. The grower and entomologist as well as the plant pathologist should keep this in mind and if there is any doubt regarding the symptoms, an identification should be requested from a nematologist. Considering the comparative youthfulness of this branch of science, it should be remembered that even the specialists' views concerning the relative significance of these forms are subject to a great deal of change and modification.

It has already been pointed out that nematodes constitute an extremely large and varied group of animals, divided into many different families. With some exceptions, the plant-parasitic forms belong to only three of these families; the Tylenchidae, the Aphelenchidae, and the Dorylaimidae. The members of all three of these families are provided with a stylet with which they feed. This organ appears to be fully effective in puncturing the plant tissues; and in obtaining the food required by these parasites by sucking. Furthermore, many types of plant-parasitic nematodes appear to induce the host plant to produce their particular food requirements by injecting into the plant tissues the

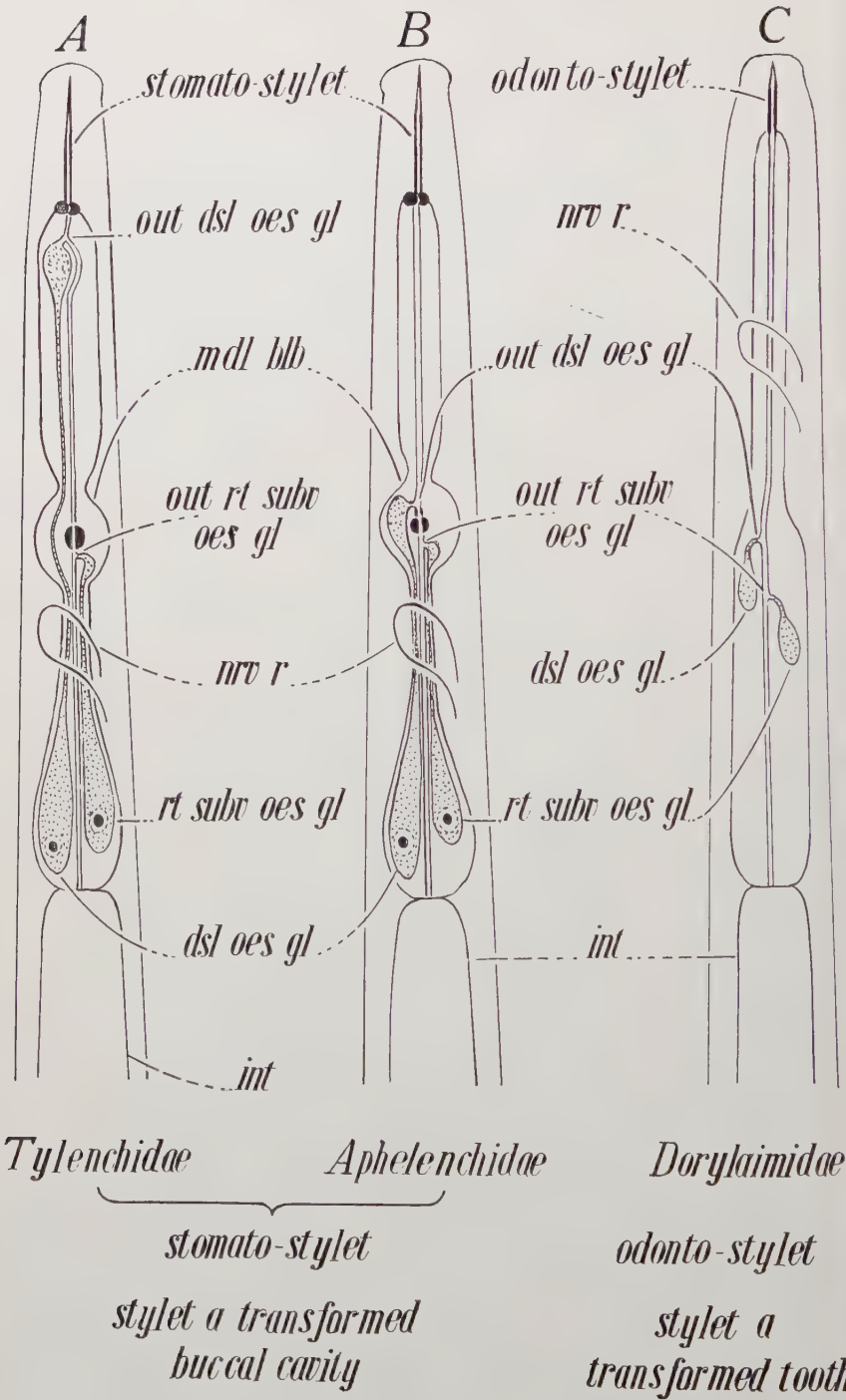

Figure 11.—Schematic drawings to explain the main differentiating characters of the three groups of nematodes to which most plant-parasitic forms belong. A. Tylenchidae, B. Aphelenchidae, C. Dorylaimidae. *dsl oes gl*, dorsal oesophageal gland; *int*, intestine; *mdl blb*, middle oesophageal bulb; *nrv r*, nerve ring; *out dsl oes gl*, outlet of dorsal oesophageal gland; *out rt subv oes gl*, outlet of right subventral oesophageal gland; *rt subv oes gl*, right subventral oesophageal gland.

secretions of their large esophageal or salivary glands. For this purpose the stylet is used as an injecting needle.

The stylet of the tylenchs and also that of the aphelenchs is called a buccal stylet or "stomato-stylet". It is assumed to have originated through the transformation of the buccal cavity of the ancestors of these two closely related families. The sclerotized walls of the buccal cavity of these ancestors are assumed to have been amalgamated and so to have formed a perforated tube, or the buccal stylet presently seen in these forms. (Figs. 11 & 12). In the dorylaimids, however, which represent a group of very different origin and relationship, the stylet is assumed to be a transformed tooth and is therefore termed an "odonto-stylet." (Fig. 13).

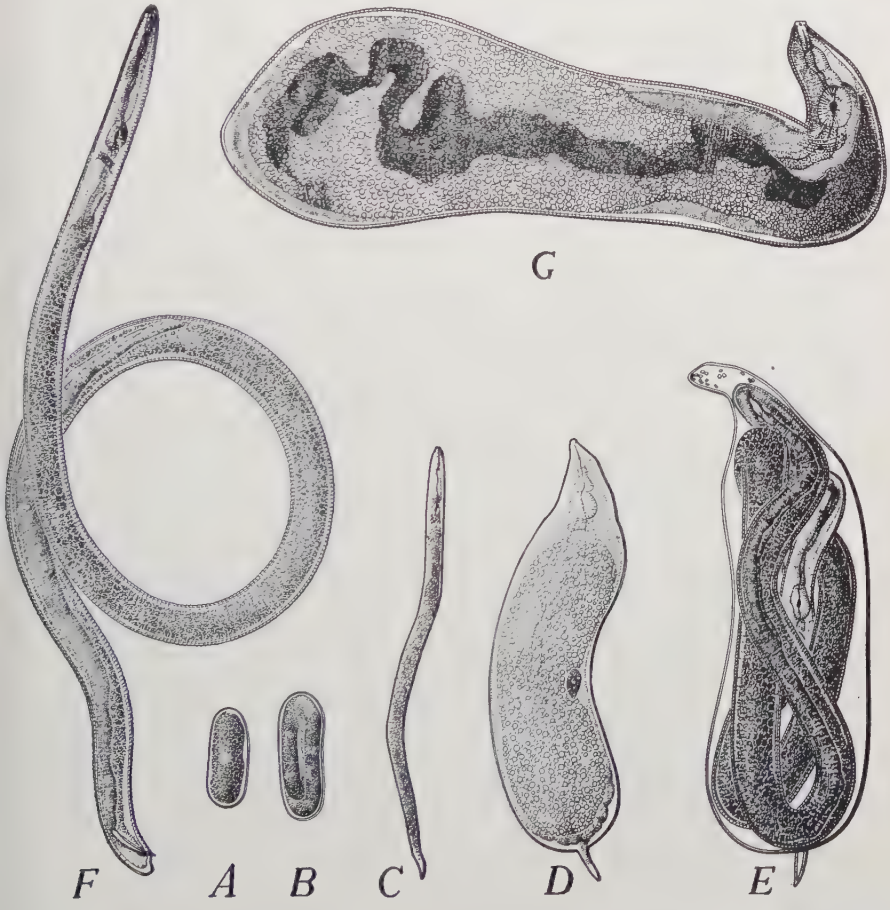

Figure 12.—Drawings of various developmental stages of the root-knot nematode. *A*. Unsegmented egg; *B*. egg containing larva; *C*. migratory larva free in the soil; *D*. sausage-shaped larva living sedentary in the root; *E*. larval molt containing fully developed male; *F*. adult male; *G*. young female. × 140

Figure 13.—Photomicrographs of developing larvae of the root-knot nematode in roots of balsam (*Impatiens balsamina* L.) *A*. Swollen portion of a root with numerous larval nematodes arranged around its axial cylinder (× 25); *B*. single young larva, its body only slightly swollen but the root tissue cells around its head end already enlarged to form the so-called giant or nectarial cells. The immigrating root-knot nematode larva in settling down for its permanent, life-long location injects secretions of its oesophageal glands into the root tissue. These injections stimulate the cells to increased growth and, by secretion, to the production of a type of fluid food which is directly assimilable by the host. It appears that this food material is of such comparatively simple structure that a regular digestion in the intestine of the parasite is not further necessary. The intestine of these parasites appears to be mainly a storage organ for food reserves and the rectum and anus are often vestigial (× 63); *C*. same as *B* but a later stage (× 100); *D*. same as *B* and *C* but still a more advanced stage than *C*. The molt of the larva is seen as a faint mark surrounding its body (× 100).

The tylenchs and aphelenchs include the most outstanding plant nematode pests, many species of which often occur in very large numbers. The two families are differentiated mainly by one character. In the tylenchs the dorsal esophageal or salivary gland empties into the alimentary tract a short distance behind the buccal stylet (Fig. 11), while in the aphelenchs it empties into this tract in the middle esophageal bulb just in front of its valvulae (Fig. 12).

The dorylaims occur in numerous genera and species in soils everywhere. Many live parasitically on and in plants, even in the leaves and other above-ground parts, but they rarely occur in such great numbers in an attacked plant as do certain parasitic aphelenchs and tylenchs. All dorylaims appear to lead a migratory mode of life although some occur in plant tissues apparently quite sedentary, their body rolled up in a more or less tight spiral.

The most prominent characteristics of the tylenchs and aphelenchs, in comparing them with dorylaims, is their decidedly greater size and the more highly developed function of their oesophageal glands. These characteristics doubtless are directly related to the much more pronounced pathogenicity of the group. For instance, in many species of tylenchs and aphelenchs, the secretions of these glands are known to have a poisonous effect on the host in addition to inducing the host tissues to produce directly assimilable fluid for use as food by the parasite. The presence of these enlarged and strongly functional oesophageal glands in the tylenchs and aphelenchs appears, in general, to indicate an extra-oral digestion and, correlated with it, a transformation of the intestine into an organ designed mainly for storage of food reserves. It is on this account that they are able to feed by inducing the host tissues, through glandular injections, to produce directly assimilable food. The dorylaims, on the other hand, suck the cell contents directly from the host tissues: these cell contents, in turn, are digested and broken down to simple assimilable forms of food in their intestine.

In reviewing the more important plant-parasitic nematodes, it appears best to begin with those types capable of attacking the growing roots of plants. Certain species, of course, are of far greater economic importance than others. It is with these species that we will first deal.

THE ROOT-KNOT NEMATODE

The root-knot nematode (*Heterodera marioni* [Cornu] Goodey) is considered the most important of this group. Its extended distribution through the tropics, subtropics, and temperate regions and its occurrence in greenhouses everywhere, make it one of the most widely distributed and common agricultural pests. It has long been known in Florida. Neal states that the disease, as such, was known to occur here as early as 1805, although the causitive organism, the nematode, was not discovered until 1879, and was first definitely established as occurring in Florida in 1889. While it doubtless is now present in all sections of the State it is particularly bad in those areas where sandy and peaty soils prevail, where it causes damage in various ways that may well be estimated at several million dollars annually. It also has been reported

to occur in almost every State of the Continental U. S. A. Although this organism was formerly thought incapable of surviving the winter in the northern part of our country, this is a misconception, for experiments and observations show it is fully capable of withstanding extreme cold when in the soil, and of surviving temperatures as low as 10°F. if exposed. Root-knot does not cause such extensive damage farther north, however, as it produces under warmer climatic conditions, apparently because northern summers are short and cool, thus preventing the development of more than one or two generations.

In the description of the life cycle of the root-knot nematode we may best begin with the preparasitic larva (Fig. 12C) after it has hatched from the egg (Fig. 12 A & B) and migrated through the soil until it has reached a root tip, where it makes its entry. After migrating to the axial cylinder of the root, it becomes sedentary, (Fig. 12A) and, with its short buccal stylet, injects the secretion of its oesophageal or salivary glands into the tissue of the roots. Thereupon the cells of the root begin to form from three to five so-called giant cells at the injection point around the oral opening of the nematode (Fig. 13 B-D). These cells are also called nectarial cells from which the nematode absorbs its food during its entire life. With the intake of food the larva begins to swell rapidly, first becoming sausage-shaped (Figs. 12 D and 13 B-D) and then growing to a pear-shaped, whitish body (Figs. 14, 15 & 16). At this stage of development it may be so large in some instances that it can be seen with the naked eye (Fig. 17). Under favorable conditions this development may take three to four weeks, but a much longer time is often required, particularly when the temperature is suboptimal. The full-grown female produces eggs (Fig. 18 B) which are deposited in a yellowish-brown, jelly-like substance which flows from the female genital opening prior to egg production (Figs. 14 & 16). The number of eggs produced varies a great deal. The average is considered to be 400 to 500, but this number may be much smaller or considerably larger since over 2.000 eggs have been observed to be produced by a single female. This variation in the number of eggs is caused not only by temperature conditions, but also by the kind of host, some plants being more suitable than others. Each egg may develop a larva (Fig. 12 A & B), which will break the eggshell and become free in the soil by the cracking of the root or at the time of its decay. The egg stage is unquestionably the most resistant, and it is in this stage that the nematode may survive long periods of adverse conditions. A larva free in the soil succumbs quickly to adverse conditions such as lack of moisture, excessive heat, direct sunlight, or cold. Males develop under certain conditions but they appear to play no role in the production of progeny. They are slender, eel-like organisms of very different shape from the females (Fig. 12 E & F). Their development is very interesting; instead of growing to a pear shape like the females, a male larva at the sausage-shaped stage is transformed into a threadlike, cylindrical nematode folded and wound up inside the larval molt from which it finally escapes as a mature male.

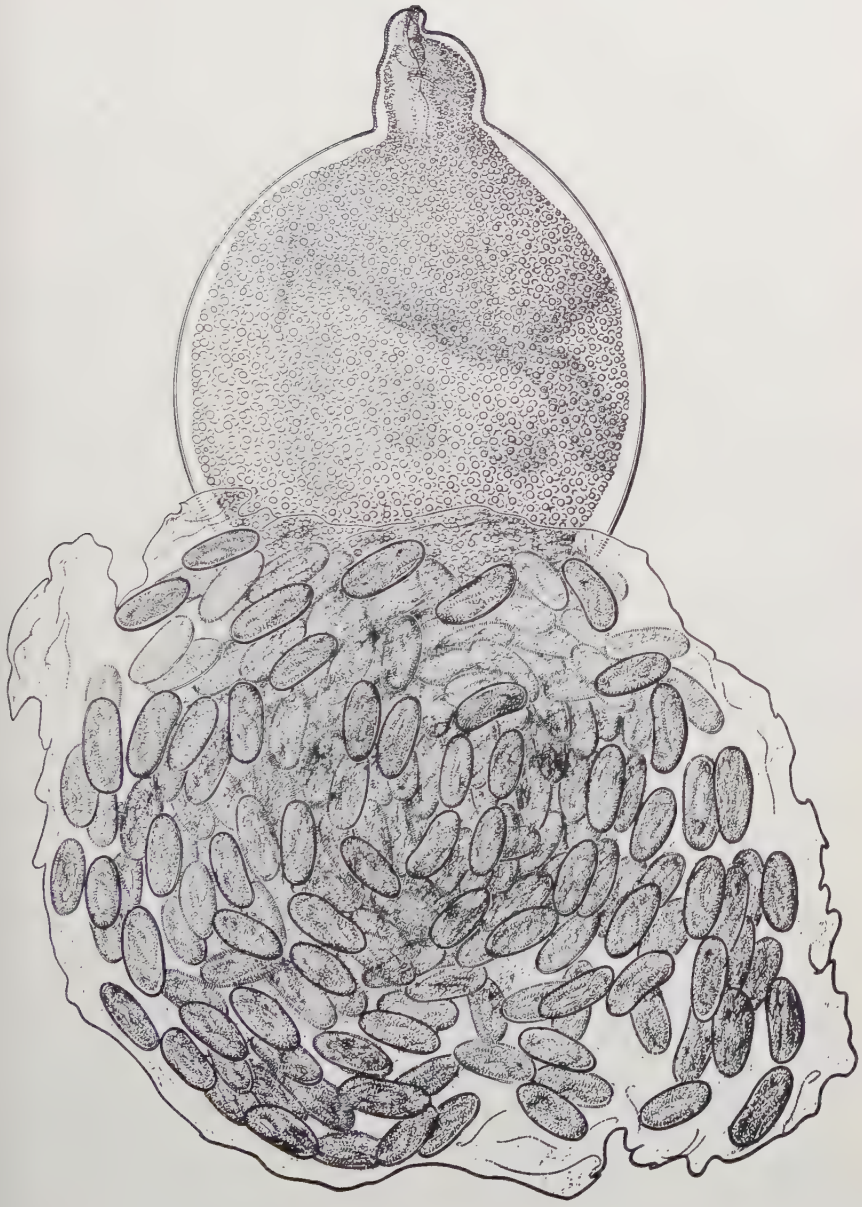

Figure 14.—Drawing of an adult female of the root-knot nematode with attached egg mass embedded in a protective jelly. × 115

Figure 15.—Photomicrograph of a swollen root section of the balsam plant *(Impatiens balsamina)* with numerous adult females of the root-knot nematode; the eggs of one specimen can be clearly seen. × 50

It is evident that during its life cycle the root-knot nematode passes a prolonged period inside the host plant, possibly from three to five months. The egg and the migratory larvae are the only stages that may normally occur free in the soil. In control procedures this is an important point. Fumigants applied to the soil sometimes reach only larvae and eggs free in the soil, while specimens inside a root, particularly if it is woody, may not be affected. The complete uprooting of plants will eliminate all stages inside the roots—eggs, larvae, and adults—if the roots are destroyed. The development of the larvae is interrupted if the root on which they are feeding is disturbed, and they

Figure 16.—Photomicrograph of two adult female root-knot nematodes in a balsam plant root *(Impatiens balsamina)*; the giant or nectarial cells are seen as darkened cell masses in the axial cylinder of the root; the jelly mass secreted by the females is seen surrounding the broad posterior end of the females, the pointed head end of which is embedded in (upper specimen) or directed toward (lower specimen) the giant or nectarial cells. × 135

will perish when the root dies. In fleshy roots, however, such as peony, and in rhizomes, corms, tubers, and bulbs development may go on, if these plant parts are stored or otherwise kept under conditions favorable to the nematode. This situation explains the many opportunities for the distribution of this pest through infected plant material as, for example, nursery stock and root crops such as potatoes, carrots, etc. The spread of the larvae by active migration is slow.

Over 1700 different plant species are known to be attacked by the root-knot nematode. However, they exhibit a wide variation in the

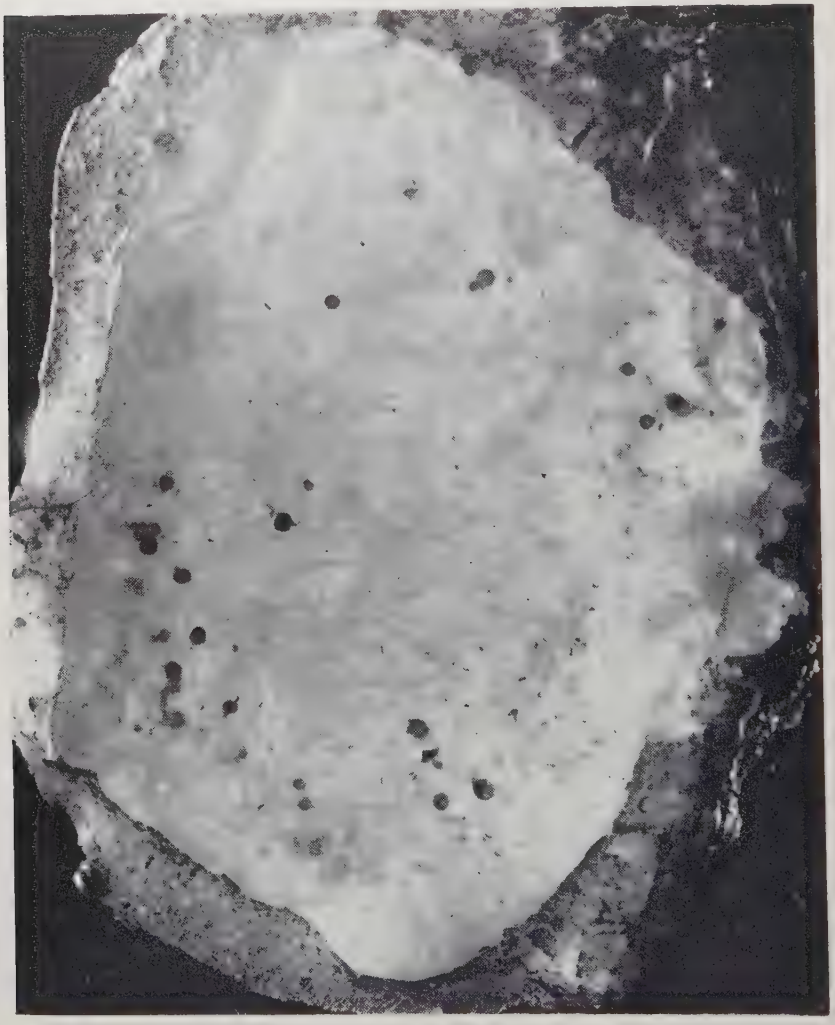

Figure 17.—Photomicrograph of female root-knot nematodes embedded in the tissue of a potato of which a thin surface portion was sliced off. In potatoes these adult females may often be recognized with the naked eye. × 3

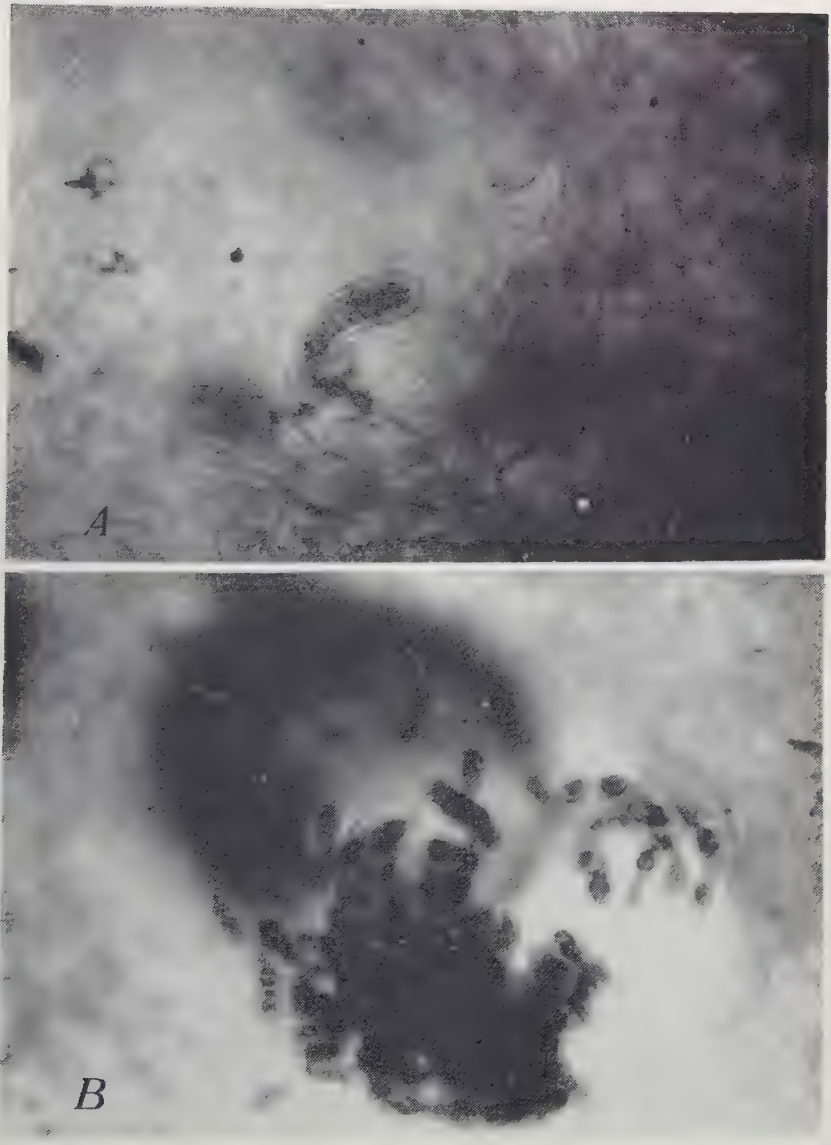

Figure 18.- *A.* Photomicrograph of a larval specimen of the root-knot nematode in the tissue of the same potato shown in Figure 17. *B.* Photomicrograph of an egg mass of the root-knot nematode in the tissue of the same potato as shown in Figure 17. × 85

degree of susceptibility to attack and in the seriousness of the disease that follows. Thus some suffer severely from a slight attack (e.g. cyclamen) while other species are very tolerant (e.g. mulberry tree). It should be mentioned here that germinating seeds and young seedlings are particularly attractive to the root-knot nematode larvae (Fig. 8) including even seedlings of plants otherwise immune or highly resistant. Seeds should therefore never be planted in soil badly infested by the root-knot nematode or by any other plant-pathogenic nematode form, nor should such soil be used for seed-testing purposes. Germination will be poor and most of the emerging seedlings will be sickly. Thus the seedlings of the tung oil tree (*Aleurites fordii* Hemsl.) are very susceptible and may die from an early infection but after the first year may recover and then develop a high degree of resistance.

It was mentioned earlier that in some plants the root-knot nematode breaks through the root surface so that the egg-producing females protrude from the root and may then be seen with a hand lens as globular, whitish bodies with yellowish or brownish egg masses attached. Sometimes not even swellings are formed. Under such conditions the parasite is even more injurious than in those cases where a smooth, uncracked gall without necrotic tissues is formed. This is due to the fact that roots cracked or opened by the action of this nematode are at once invaded by a whole group of secondary agents including other nematodes, fungi, and bacteria and this usually leads to quick decay. Plants thus attacked naturally suffer much more than those which form "smooth," uncracked or, if such an expression is permitted, "healthy" galls.

Frequently growers or scientific workers looking for this nematode with the conception that galls or knots are its symptoms, have often considered the nematode absent because there were no galls. Thus they have missed the root decay initiated by this nematode which is usually much more serious than the galls.

SEDENTARY TYPES

This leads us to other sedentary types of plant-parasitic nematodes of roots, namely the sugar-beet nematode and related species like the golden nematode of potatoes. In these species even the growing larvae normally protrude from the root surface and the adult females generally hang on the outside of a root. In contrast with the root-knot nematode, the members of the sugar-beet nematode group have a characteristic which makes their control much more difficult. The old females, before dropping from the root or tuber, turn from a whitish color to brown as their cuticle is transformed into a thick, protective cover with a variable number of eggs and larvae contained inside. Females thus transformed are then called "cysts" and may remain in the soil for years, releasing active larvae over a period of years. This phenomenon not only complicates control of these pests when crop rotation schemes are used but also when fumigants are used, since these "cysts" are highly resistant to the action of chemicals. We know of no species of this group occurring in Florida but are convinced that at least one form, *Heterodera*

weissi, n. sp.[6] (Fig. 19) may be present. It is found on various species of knotweeds and is known to us to occur in numerous states east of the Rocky Mountains, as far south as the Delta section of southern Missouri and the region of Ridgeville, Georgia.

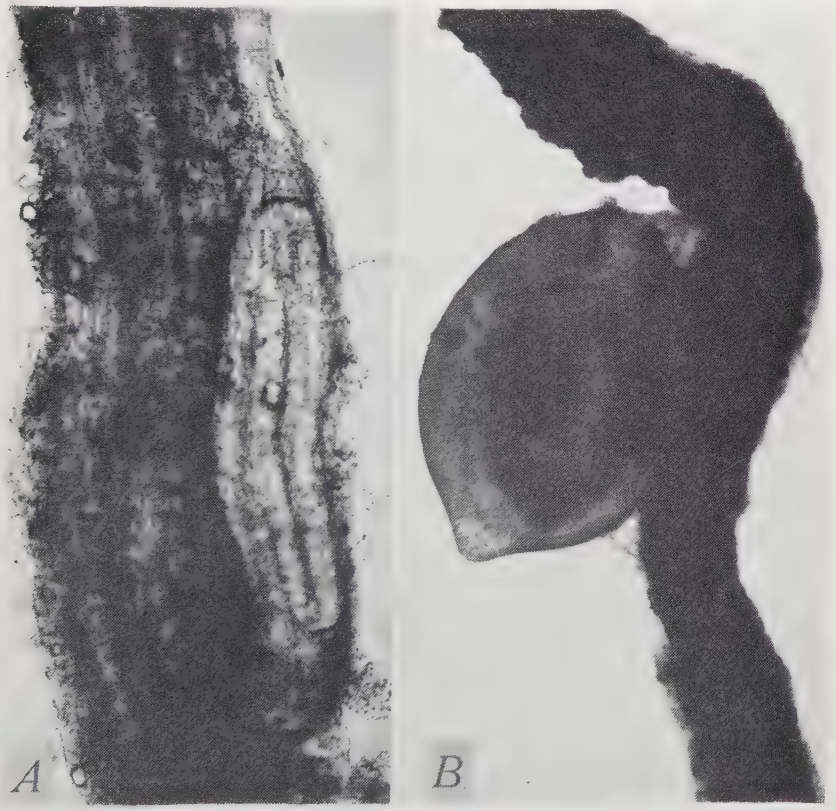

Figure 19.—*A*. Male of *Heterodera weissi* n. sp., the knotweed heterodera, located under the surface of a root of *Polygonum pensylvanicum* L. *B*. Female *Heterodera weissi* n. sp., as it hangs on a root of the same knotweed as above; × 100.

The root-knot nematode, together with the various species of the sugar-beet nematode group, represent sedentary root parasites which are

[6] *Diagnosis: Heterodera* with small, lemon-shaped cysts (330 to 404μ × 590 to 617μ) with protuberant vulva; outside surface of cyst wall with network of transverse, meandering and anastomosing ridges, separating depressions which are mostly elongate, somewhat rhomboidal in shape. Male 1.010-1.34 mm. with annulated, well set off, semi-spherical head; buccal stylet of about 28-29μ; ventral terminal anus with protruding lips; spicula 34μ; gubernaculum 10μ; α = 35-36; β = 8.4-11.8; γ = about 0. Eggs 32 to 42μ × 81 to 114μ. Preparasitic larvae 0.320 to 0.388 mm, their head with 6 annules. Known to infect the roots of various species of the genus *Polygonum* in the United States east of the Rocky Mountains. *Type host: Polygonum pensylvanicum* L.; *Type locality:* Plant Industry Station, Beltsville, Maryland.

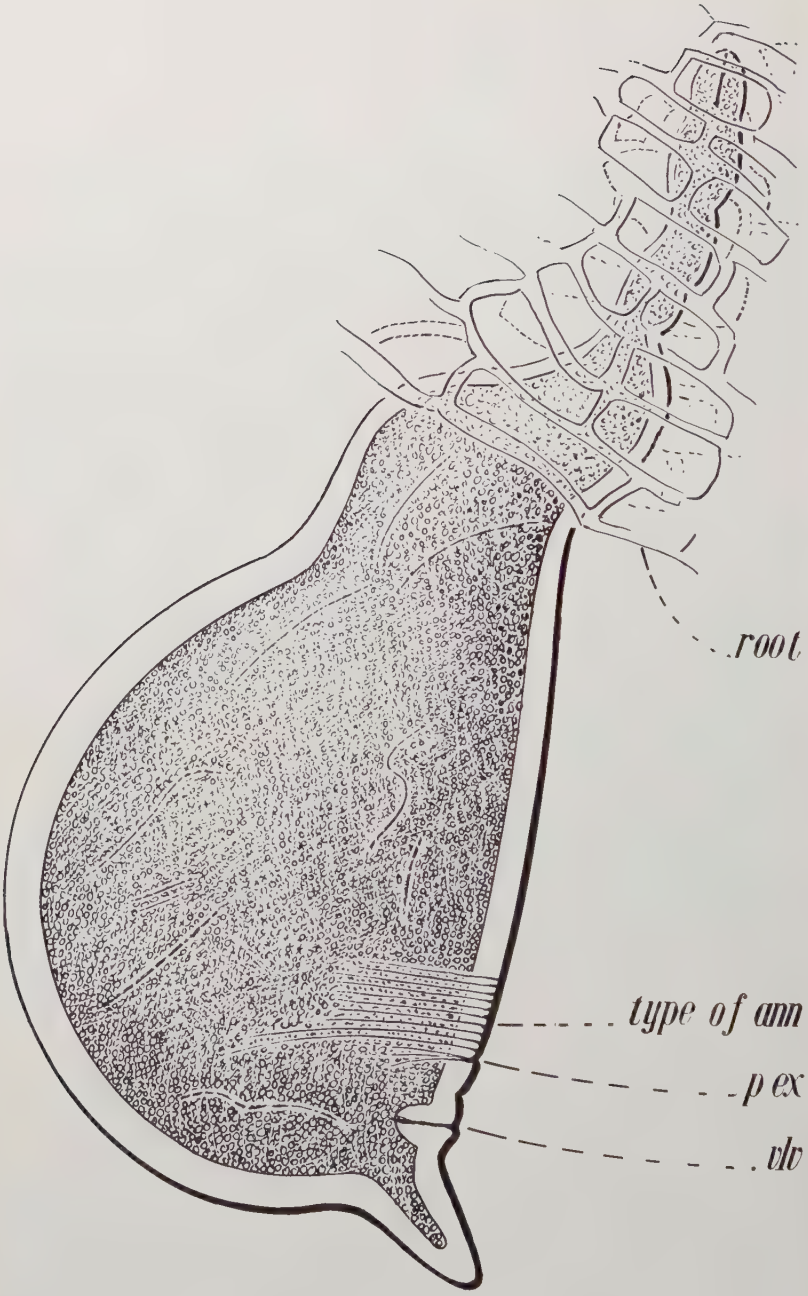

Figure 20.—Drawing of a female of the citrus nematode, *Tylenchulus semipenetrans* Cobb, attached to a root. The elongated head end is shown inserted deep into the root tissue so that the cells of the axial cylinder are reached. *p ex*, excretory pore; *type of ann*, annulation of cubicle, only partly drawn; *vlv*, vulva.

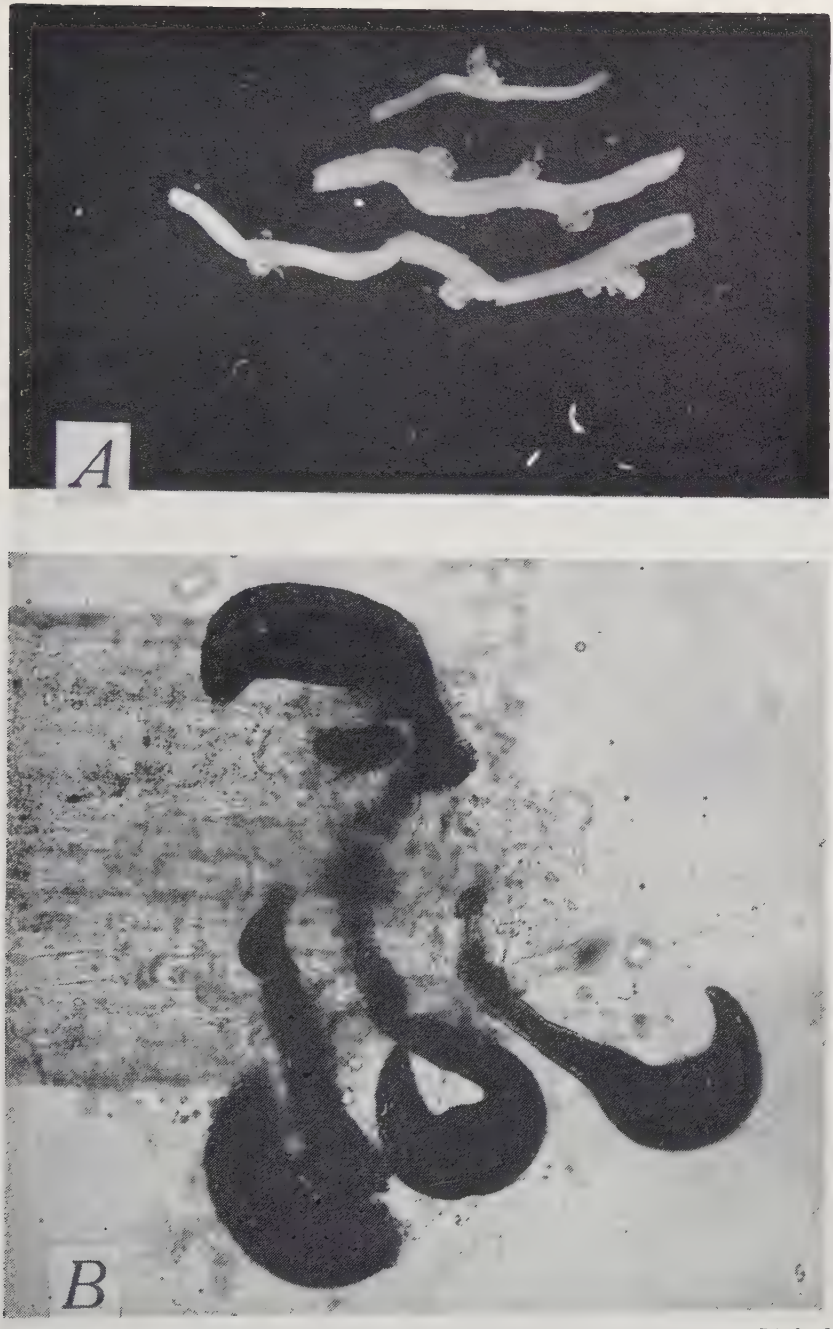

Figure 21.—The kidney-shaped nematode, *Rotylenchulus reniformis* Linford. *A*. Pieces of roots of *Jacquemontia tamnifolia* L. Griseb with specimens of the kidney-shaped nematode attached to them. Their body is covered with small soil particles which are held together by a glabrous secretion produced by the nematode. Thus, the uniformed will never suspect that the small globular bodies attached to these roots are not parts of soil but hide a sedentary root-parasitic nematode. × 24. Sample collected by A. L. Smith at Cuthbert, Ga. *B*. Tomato root infected with the kidney-shaped nematode; the glabrous cover surrounding the nematodes has been teased off to expose their bodies; their elongated neck, with which they penetrate the root, may be seen. Tomato plant experimentally infected in a greenhouse. × 170.

all combined in a single genus, all closely related and difficult to differentiate. The adult female has a swollen, spherical, lemon- or pear-shaped body, unlike most other nematodes, while the male retains a threadlike body shape.

But this group is not the only one in which sedentary life has resulted in transformation of the female by globular inflation. The same phenomenon is seen in other genera of quite different origin and relationship; an outstanding example being *Nacobbus*, a form only recently described by Thorne and Allen from California. Here the female has a protruding vulva of such length that it resembles a tail; this enables it to deposit the eggs outside the root since the protruding tail-like vulva appears always so located as to reach the root surface.

The citrus nematode (*Tylenchulus semipenetrans* Cobb) is still another example of a swollen, sedentary type of root parasite. It belongs to still a different taxonomic group from the two already mentioned. In this instance the roots are attacked from the surface and only the elongated anterior portion of the body penetrates the root tissue, while the posterior part swells, as shown in Fig. 20. Here again, however, the male is of very different shape and appears not to feed at all. In fact it hardly increased in size while developing from the larval to the adult stage.

There is still a fourth type of swollen sedentary root parasitic nematode, the kidney-shaped nematode (*Rotylenchulus reniformis* Linford). The parasitic female is attached to the root surface but its body is surrounded by a spherical structure which it forms for itself by secreting a glabrous substance which also surrounds the eggs and cements together

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Figure 22.—Two different types of ring nematodes. *A. Criconemoides citri* n.sp.,[1] representing a broadly annulated type, infecting roots of the sour orange in the region of Orlando, Fla. The roots are punctured from the surface with the remarkably strong buccal stylet and the head itself is frequently buried deep in the root tissue which becomes necrotic around the organism. *B. Criconema civellae* n.sp.,[2] representing a very unusual type of nematode with its 8 longitudinal series of fringed scale-like structures on the body surface. It was found feeding on the roots of *Citrus grandis* (L.) Osbeck, the pummelo, grown in a greenhouse of the Plant Industry Station, Beltsville, Md.

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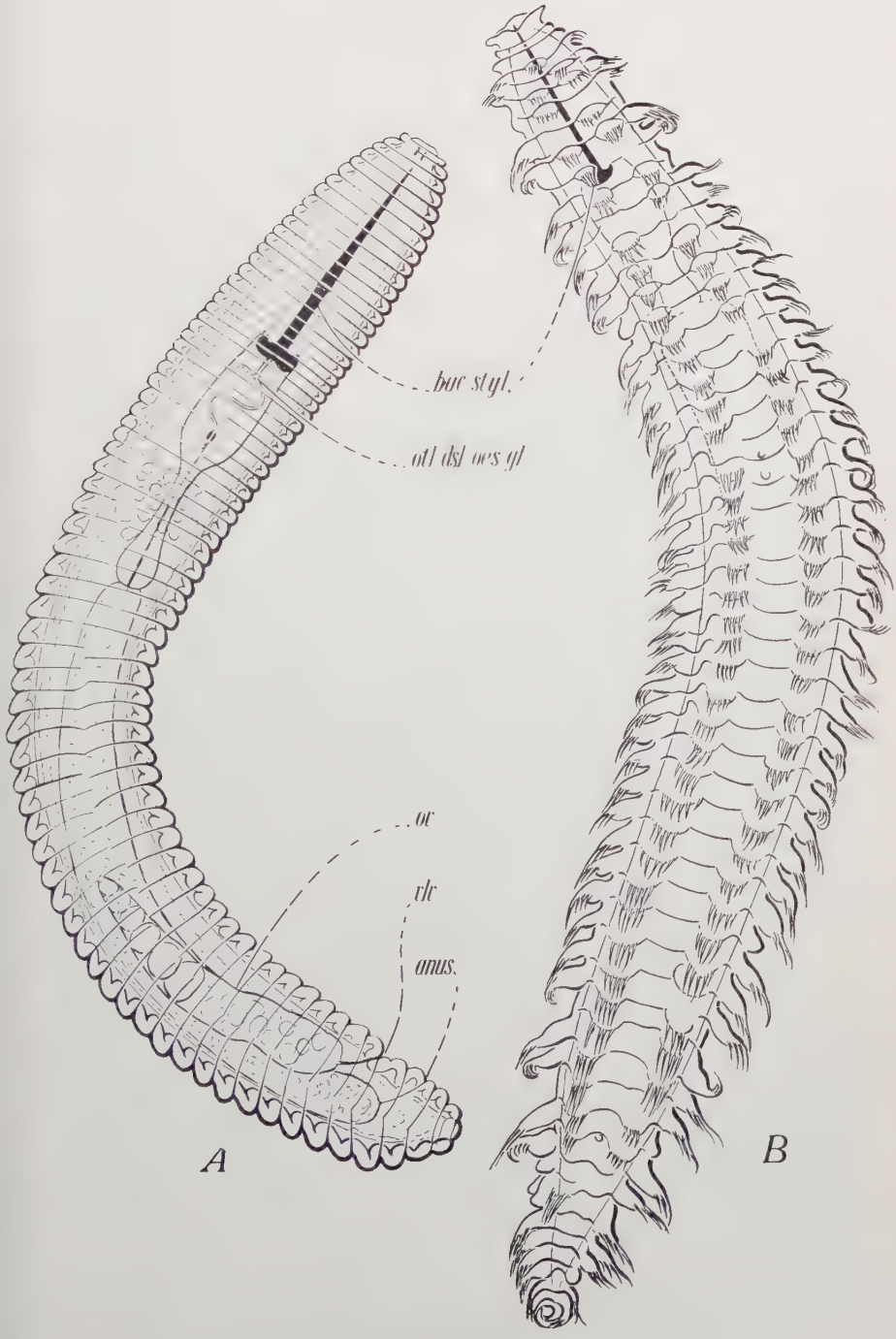
[1] *Diagnosis: Criconemoides* resembling *C. sphaerocephalum* A. L. Taylor but different because the anastomosis of the annules along the lateral line is simple, i.e., the annules do not break joint to form a zigzag suture as in *C. sphaerocephalum;* buccal stylet shorter, only 50μ long; middle bulb of oesophagus only about ½ width of body cavity; isthmus and terminal bulb much longer than in *C. sphaerocephalum.*

Measurements: Total length of ♀ = 0.252mm; a = 8.4; β = 2.3; γ = 31.5
Type host: Citrus aurantium L.; *Type locality:* Orlando, Florida.

[2] Named for Mrs. Civella Adams Chambliss, Scientific Aid in the Division of Nematology, U. S. Dept. Agriculture, in recognition of her first finding of various forms of this group of plant-parasitic nematodes so difficult to locate. The new species is provisionally placed in the genus *Criconema* Hoffmanner & Menzel 1914. *Diagnosis: Criconema* resembling *C. octangulare* (Cobb 1914) Taylor 1936 but different because each scale of the 8 longitudinal series has a fringe of from 4 to 6 stiff, outward- and backward-pointing setae on its posterior edge. Annules numbering from 58 to 62. Buccal stylet 68μ. Total length = 0.376 mm. *Type host: Citrus grandis.*

Figure 22



adjacent soil particles. We located this interesting species recently from Florida on roots of tomato and coffee weed (*Cassia tora* L.) sent to us from Quincy. As in the citrus nematode, the anterior portion of the body of the female is elongated and is inserted into the root while the reniform, main part protrudes from the surface. The male in this case also remains small and its body is not swollen. Because of its bubble-shaped glabrous enclosures covered with soil particles, *Rotylenchulus* is very difficult to see and may easily be overlooked or mistaken for globular soil agglutinations adhering to the root (Fig. 21).

Figure 23. A ring nematode (undescribed species) attacking the root of a pummelo *(Citrus grandis)* grown in a greenhouse at the Plant Industry Station, Beltsville, Md. Its head is buried in the root surface; several nearby surface cavities were probably made by the same nematode; × 75.

It is obvious that all these sedentary nematodes with inflated and obese bodies that become fixed in or on a root lose their motility and are unable to change their position and migrate. If roots containing such stationary parasites are uprooted and destroyed before the parasites are fully grown or before they have produced eggs, the source of infection is removed. Control of certain of these nematodes by a trap- or catch-crop is based on these considerations. Since only the preparasitic, larval stage of these sedentary forms is able to migrate, the spread of these various types by their own means is very restricted. Thus long distance travel is entirely one of transportation by such carriers as wind, water, and particularly man, who spreads them with plant material of all kinds and with soil.

There exist other sedentary root parasitic nematodes which in contrast with the foregoing groups have preserved a certain, though reduced,

Figure 24.—*Procriconema* sp. attacking the roots of slash pine seedlings (*Pinus caribaea* Morelet) near Olustee, Fla. The arrows point to groups of nematodes attached to blinded root tips; × 25.

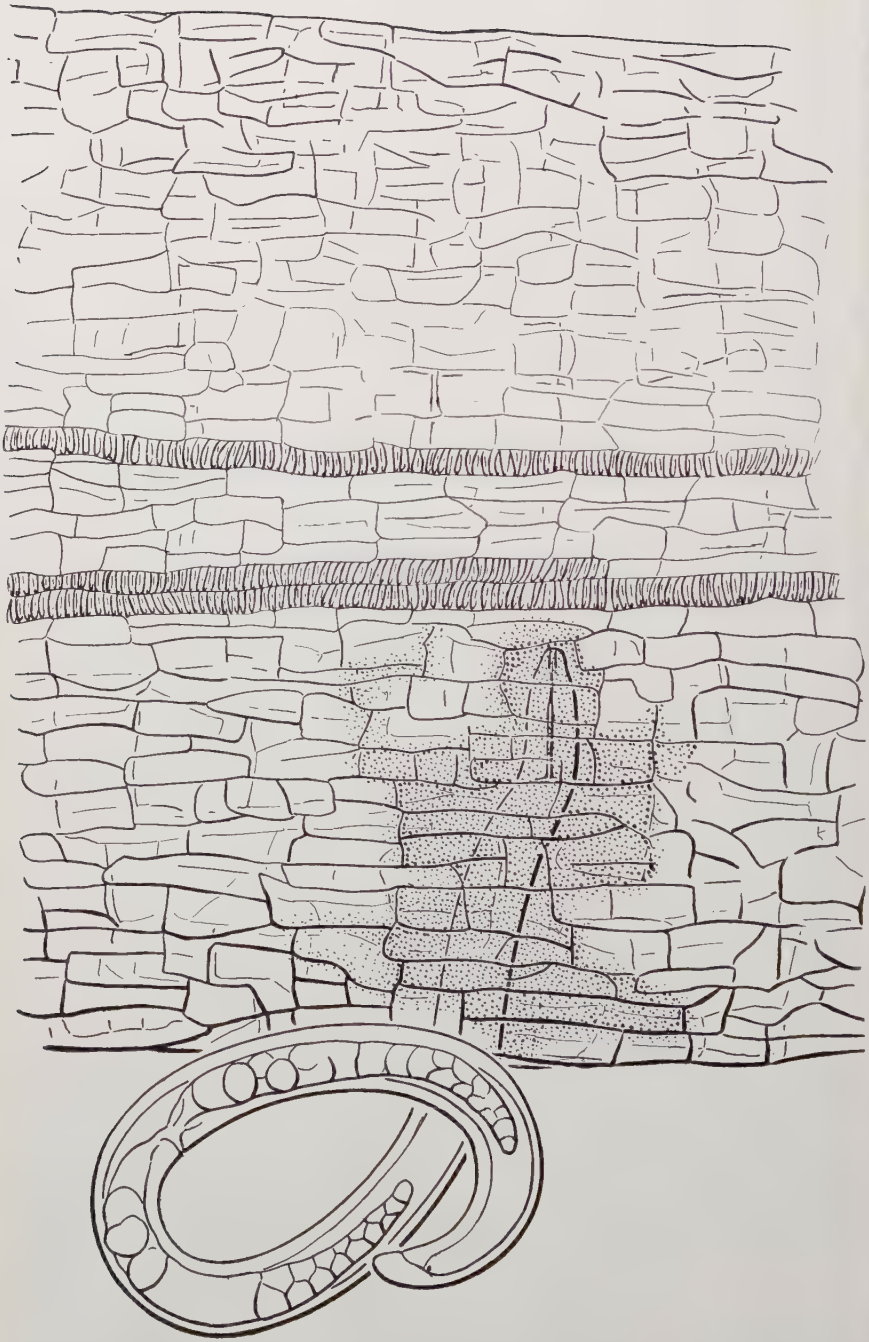


Figure 25.—Drawing of a spiral nematode (*Helicotylenchus* sp.) attacking a rootlet of sweet clover (*Melilotus* sp.) The anterior end of the nematode has deeply penetrated the root tissue; dotted region indicates the extent of cell necrosis evidenced by discoloration; specimen collected by F. R. Jones, Madison, Wis.; × 333

motility: they are called ring and scale nematodes and include various genera and numerous species belonging to the Criconematinae and other related groups (Fig. 22 A & B). They too are ecto-parasites, puncturing the surface of roots (Fig. 23) and other subterraneous parts with their stylets which are strong and often extremely long. All members of this group are short and stout and heavily annulated. In some, the annules are provided with retrorse scales or spines, or a combination of the two. This annulation and its armature obviously enables the members of these groups of rather unusual looking nematodes to get the necessary support and resistance in the soil while they press their stylets and heads into the plant tissues. Locomotion also is possible mainly through the use of the annules and their scales and spines. Certain types of these groups (e.g. *Procriconema* Micoletzky) are of pronounced, sedentary habit (Fig. 24). They retain their moulting skins, which make an additional protection for their bodies while quite permanently attached to a root. Locomotion of these animals with a double sheath around them would be extremely difficult.

Finally there are root-surface parasites with well developed locomotive ability which nevertheless pass a sedentary existance on roots for extended periods. One group of these are the ancestors of the kidney-shaped nematode previously mentioned. They are forms widely distributed and because their long body is usually kept in the shape of a spiral they are called spiral nematodes (e.g. *Helicotylenchus* Steiner; *Rotylenchus* Filipjev). Their buccal stylet is quite long and strong and well fitted for inserting into plant tissue. Often the head and part of the anterior portion of the body are also inserted into the root (Fig. 25). It is thought that this procedure is made easier by the retention of their bodies in a ventrally curved spiral of one to two turns. These spiral nematodes are still little known but are of wide distribution. Where numerous they may seriously interfere with plant growth. *Helicotylenchus nannus* Steiner is a small but very common species in the southeastern U. S. A., including Florida.

Of similar behavior are the pin nematodes (genus *Paratylenchus* Micoletzky). The body of this genus, particularly that of the female, is ventrally curved but to a lesser degree than in the spiral nematodes, possibly because they are much shorter. All members of this group are unusually small, and for this reason they frequently have been overlooked. It now appears that they are rather common, sometimes occurring in enormous numbers. The buccal stylet of the various species is always long, although the length differs considerably. This organ may be inserted into the plant tissue for a considerable portion of its length, a fact well shown in the folds of the esophageal canal when the stylet is retracted. The males in this group are all of a vestigial character, in some species very rare or even unknown, and their stylets are usually weak and degenerate (Fig. 26).

MIGRATORY NEMATODES

In contrast to the various types of fully or partly sedentary root-parasitic forms, there exists a large group of migratory nematodes be-

longing to several different genera and families. These may be classed into those forms that enter the tissues, move through the root and live inside it, as well as others that puncture a root and feed on it from the outside.

The most important of the first mentioned group, i.e. those of endoparasitic habit, are those species belonging to *Pratylenchus* Filipjev and related genera, or the so-called meadow nematodes. We know of at least four different species of *Pratylenchus* from Florida alone. Meadow nematodes are also widely distributed elsewhere. They attack the roots, tubers, rhizomes, corms, or bulbs of various crops. Occasionally they are also found in stems. A short, stout body and a strong buccal stylet make them migratory, tissue parasites, *par excellence*. From an economic point of view they are major pests. Unfortunately, their significance, common occurrence, and widespread distribution have been almost completely ignored until very recently. The various species are difficult to distinguish and their classification is still greatly confused. A form attacking the Irish potato was recorded as one of the first plant nematode pests in this country. It is *Pratylenchus scribneri* Steiner which was observed in 1889 by F. Lamson Scribner on potatoes in Tennessee. It was not given a name then, but recently has been established as a true species. Observed in different states east of the Rocky Mountains, it appears to occur exclusively on potatoes. A second species, *P. leiocephalus* N.Sp., well characterized by the angular contour of its head, has been found on potatoes in Florida as well as on a variety of other crops. (Fig. 27). While these two species are monosexual forms, there are other species which are bisexual. In entering and migrating through root tissues they destroy them by breaking through cell walls and feeding on their contents with oganisms of decay following in their wake. Root tissues penetrated by meadow nematodes usually exhibit necrotic lesions

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Figure 26.—*Paratylenchus elachistus* n.sp.,[1] a pin nematode that was found attacking the roots of ramie (*Boehmeria nivea* (L.) Gaud.) in the region of Clewiston, Fla. Material collected by W. D. Wylie, December 1943. *A.* Female; *cer ppl*, cervical papilla; *lat fld*, lateral field, × 500. *B.* Head end of female; *dsl oe gl*, dorsal oesophageal gland, ampulla outlet; *subv oe gl*, subventral oesophageal gland outlet; × 1800. *C.* Male; *phas*, phasmid (?); × 500.

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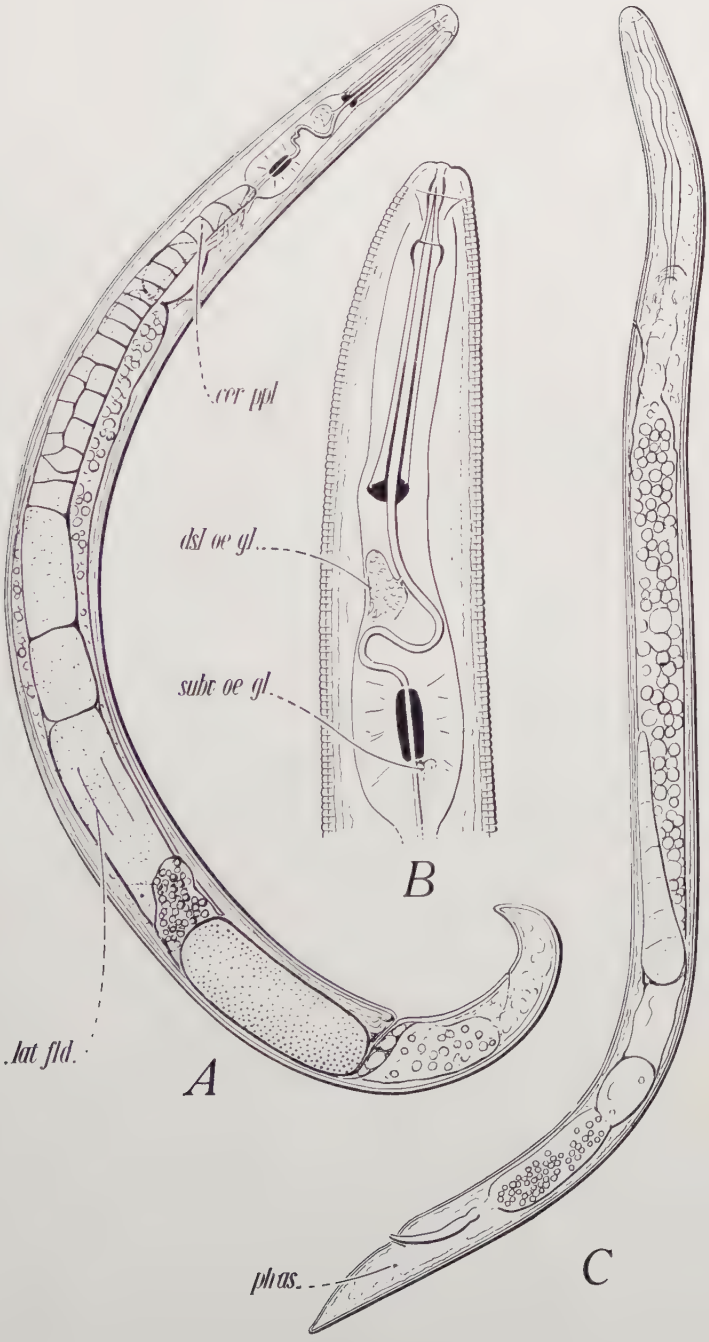
[1] *Diagnosis: Paratylenchus* resembling *P. besoekianus* Bally & Reydon 1931 and *P. bukowinensis* Micoletzky 1922 but different from the first *(a)* by its weaker but slightly longer buccal stylet (21-22μ in *P. elaschistus*, 18.8μ in *P. besoekianus)*; *(b)* by complete absence of a postvulvar uterus branch; *(c)* by its much longer ovaries which in most specimens reach forward to the nerve ring, not infrequently even close to the base of the buccal stylet; *(d)* by its longer spicula (16μ instead of 12μ) and *(e)* by its shorter gubernaculum. It is different from *P. bukowinensis* *(a)* by the smaller size of the ♀ (0.234-0.304 mm as against 0.390 mm); *(b)* by complete absence of a postvulvar uterus and *(c)* by the stronger buccal stylet and its larger, more distinct basal knobs.

Measurements: ♀ total length = 0.267 mm (0.234-0.304 mm); α = 19.8 (16.9-23.5); β = 3.9 (3.6-4.2); γ = 13.1(10.5-15.0); vulva = 83.4% (82-86.6%). ♂ total length = 0.257 mm (0.222-0.248 mm); α = 26.1(23.6-30.5); β 3.89 (3.35-4.5); γ = 11.7(10.9-13).

Type location: Clewiston, Fla.; *Type host:* ramie (Boehmeria nivea (L.) Gaud.)

Figure 26



which frequently are reddish in color at first, turning dark brown to black later on. The eggs are deposited within the roots, where, not uncommonly, accumulations of specimens, including larval stages, adults and eggs, may be seen occurring as "nests". Observations show these forms to be extremely destructive (Fig. 28 A & B) since by attacking and destroying a root at a point close to the stem they render useless the entire distal portion of the organ. Certain plants try to repair the damage by forming new side roots above the attacked points. Then as new lesions are developed on these side roots still more side roots are formed with the result that root systems attacked by these nematodes frequently exhibit a bearded or matted appearance. Sometimes the cortex of roots so attacked begins to decay and then easily slips off. The axial cylinder is rarely entered. On potatoes surface pimples are formed which later change to blackish depressions. When very numerous, these pimples and depressions disfigure the tubers to such a degree that the crop is rendered unmarketable (Fig. 29). Under certain conditions, particularly in orchards and on perennials where they remain undisturbed for years, they may multiply to enormous numbers. Cases have been observed where large trees lose significant portions of their root systems by the attacks of great numbers of these meadow nematodes, with the result that branches, limbs, parts of the crown, and even entire trees show the effect by yellowing foliage, defoliation, death of limbs and branches or even of whole trees. It is difficult to estimate the damage caused by this type of nematode on plants. They cannot live on dead,

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Figure 27.—The smooth headed meadow nematode, *Pratylenchus leiocephalus* n.sp.[1] *A.* Adult female; × 333. *B.* Anterior end; note the 3 nuclei of the oesophageal glands and their arrangement; *nrv r,* nerve ring; × 500. *C.* Head end; note the angular outline of the head proper and the 3 basal knobs of the buccal stylet which are so well amalgamated as to appear as a single spherical knob; × 1222. *D.* Front view of head; *amph,* amphid, a chemical sense organ; *cph ppl,* cephalic papilla, an organ of touch; × 1222. *E.* The basal knobs of the buccal stylet as seen in optical cross section; × 1222. *F.* Tail end of female, drawing to show the annulation of the cuticle and its interruption by the lateral field; *phas,* phasmid, an outlet of a gland; × 500. *G.* Tail end; *anus; phas,* phasmid; *vlv,* vulva; note the short postvulvar uterus branch; × 500. *H.* Tail end in ventral view; *anus; phas,* phasmid; *vlv,* vulva; × 500. *I.* Egg as it is deposited; note the kidney form which is characteristic for *Pratylenchus* eggs; × 500. *J.* Egg containing larva of which the pear-shaped end bulb of oesophagus is to be seen; × 500. *K.* Egg with larva of which tail end is to be seen; × 500.

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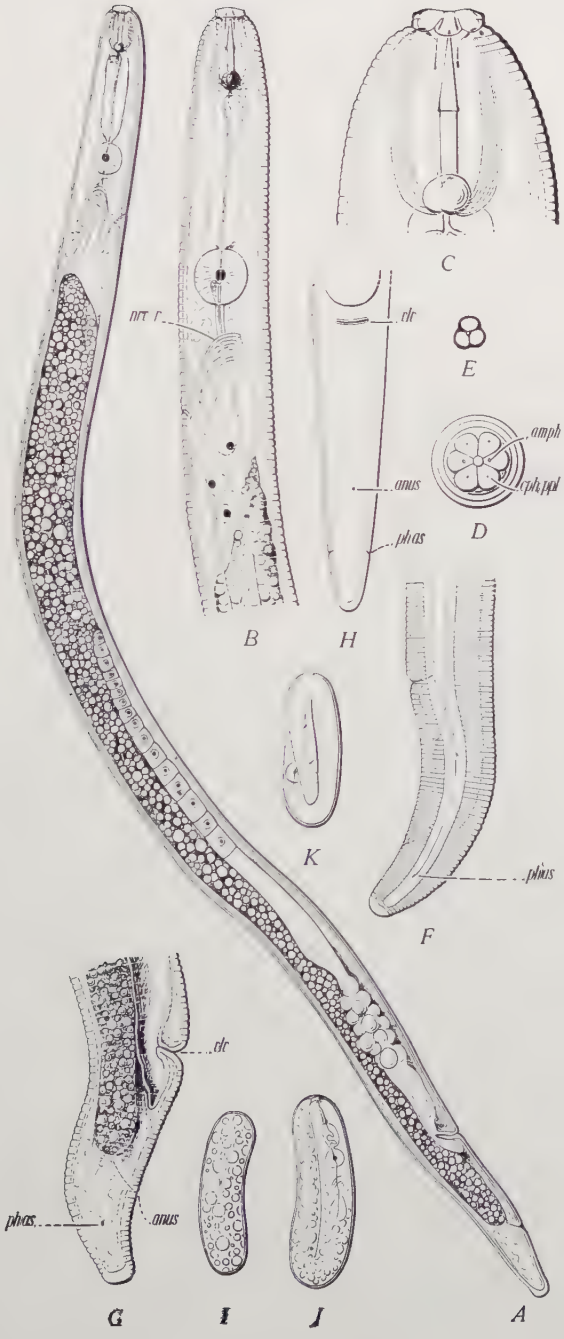
[1] *Diagnosis:* Monosexual *Pratylenchus;* head of angular contour and composed of only two annules; buccal stylet strong (18μ long), with large basal knobs, all three together forming a compact, almost single-appearing globular swelling; lateral fields narrowing behind vulva, middle striae (longitudinal grooves) uniting in front of anus and then fading in front of or at phasmid; oesophageal glands forming short, compact body, about half of which overlaps intestine. Intestine with uniform globulation; tail broadly obtuse, tip not annulated. Vulva at about 87%, or 1½ to 2 times length of tail in front of anus; ovary never reaching oesophagus, consisting of single series of about 17 oöcytes; postvulvar uterus sac very short. Eggs about 20 × 72μ.

Measurements: ♀ total length = 0.395-0.632 mm; α = 15-20; β = 5-6; γ = 17-20; vulva = 86-89%.

Type host: peanuts (*Arachis hypogaea* L.); *Type locality:* Fairhope, Ala.

Figure 27



decaying tissues and are not generally found in roots in the process of decay. Such roots abound with a variety of fungi and bacteria and so-called saprophytic nematodes, while the primary culprit has escaped to the surrounding soil or to still healthy tissue. The study of the meadow nematode is still in its infancy. Experimental work with this group is difficult because of their small size and their migratory way of life.

There exist, of course, many other nematode parasites of similar habits that belong to the same or related taxonomic groups, but the

Figure 28.—*A and B.* Root systems of two dying corn seedlings (*Zea mays* L.) heavily attacked by the smooth headed meadow nematode (*Pratylenchus leiocephalus* n.sp.) (see Fig. 27). These seedlings were collected by R. J. Humphrey near Sanford, Fla.

meadow nematodes are apparently the most destructive and most widely distributed.

MISCELLANEOUS TYPES

Since it would not be possible to mention here all these other types, only a few will be listed. Some are known to occur in Florida and other southern states. Among them the hoplolaims or lance nematodes especially should be mentioned. They appear to be mainly a tropical and subtropical group of migratory root parasites. Various species from Florida soils are known to us, while farther north only one form, *Hoplolaimus coronatus* Cobb, as yet has been observed. The lance nematodes are stout, cylindrical, rather large-sized parasites with an extremely strong buccal stylet, the tail end usually being obtuse and the cuticle coarsely annulated. They somewhat resemble the meadow nematodes in their life habits and may also occur in large numbers on roots if undisturbed for considerable periods of time. In combination with other pathogenic agents and adverse environmental conditions such as drought, a killing effect by these nematodes has been observed, particularly on seedling plants. In Florida they have been noticed as pests in forest nurseries, parasitizing seedlings of the slash pine, *Pinus caribaea* Morelet, and the longleaf pine, *Pinus palustris* Mill. Often only surface parasites, the hoplolaims may also enter the roots with the whole body. They are therefore endo- as well as ectoparasites (Fig. 30).

Figure 29.—Potatoes attacked by Scribner's meadow nematode (*Pratylenchus scribneri* Steiner). The figure at left shows a potato with a lighter infection, while that of the one at right is very heavy. The arrow in the figure at right points to a single small lesion from which alone 335 nematodes were isolated; thus the nematodes in this potato were conservatively estimated at from 12,000 to 15,000.

Other extremely interesting types are the awl nematodes, *Dolichodorus heterocephalus* Cobb (Fig. 31), and the sting nematode, *Belonolaimus gracilis* n.g. n.sp. (Fig. 32). Both are found in Florida and both feed

Figure 30.—Drawing of a root fragment of longleaf pine (*Pinus palustris* Mill.) exhibiting the posterior ends of three different specimens (arrows) of *Hoplolaimus coronatus* Cobb protruding from the broken root surface; 65 specimens were counted from a piece of root one inch long. Material collected by the author near Tifton, Ga., November 1940; × 136.

on roots which they puncture from the surface with their long needle- or awl-shaped buccal stylets. The former was observed on celery roots near Sanford. The latter was found on corn roots, also from Sanford, and on roots of slash and long leaf pine seedlings in various forest nurseries (Ocala, Brooksville, Valparaiso).

Many additional types of root-attacking nematodes could be mentioned. Usually most of them occur only in smaller numbers and are not known to cause serious diseases. Future research, however, may uncover many surprises.

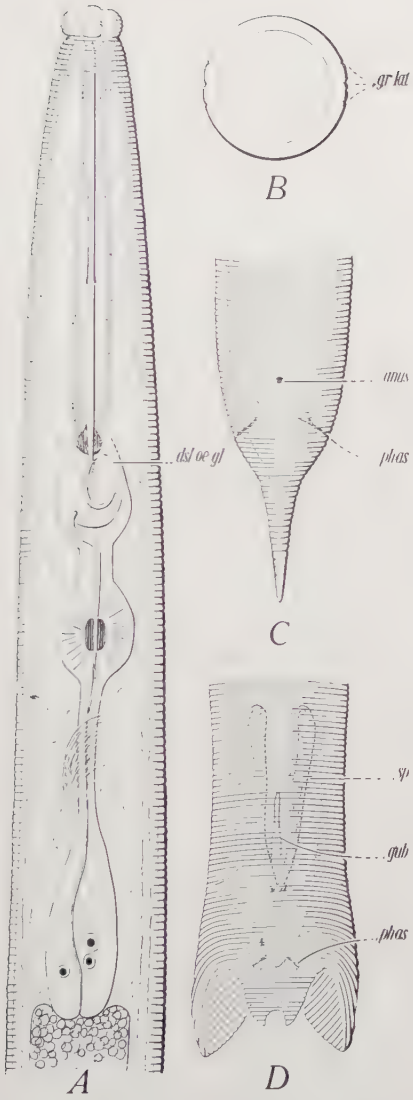


Figure 31.—The awl nematode, *Dolichodorus heterocephalus*, Cobb, an interesting type of root parasitic nematode because of its awl-shaped, long, buccal stylet and the trilobed bursa in the male. *A*. Anterior end; *dsl oe gl*, outlet of dorsal oesophageal gland; × 500. *B*. Cross section through middle region of body to show the structure of the lateral fields consisting of two longitudinal bands separated by three longitudinal grooves; *gr lat*, grooves in lateral field; × 500. *C*. Tail end of ♀ seen dorsally; *anus; phas*, phasmid; × 500. *D*. Tail end of ♂ seen dorsally to show the trilobed bursa; *phas*, phasmid; *sp*, spicula, *gub*, gubernaculum; × 500. The specimens of this parasite here partly sketched were collected by A. L. Taylor on celery roots near Sanford, Fla. in December 1943. In the "Plant Disease Reporter" of December 15, 1943, p. 707 they were recorded as a species of a genus closely related to *Paratylenchus;* however, it is now certain that *Dolichodorus* represents a separate subfamily not directly related to *Paratylenchus.*

Figure 32

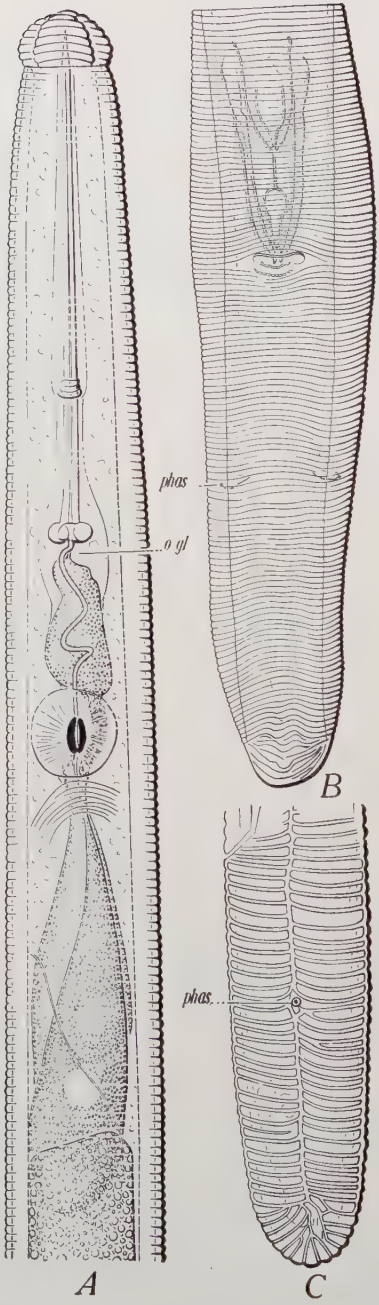


Figure 32.—*Belonolaimus gracilis* n.g., n.sp.[1], the sting nematode, an undescribed species representing a new genus. It has been observed attacking the roots of slash pine and longleaf pine seedlings in various forest nurseries in Florida. *A.* Head end; *o gl*, outlet of dorsal oesophageal gland; × 450. *B.* Tail end of ♂ in ventral view; *phas*, phasmid; × 450. *C.* Tail end of ♀ in side view; *phas*, phasmid; × 450.

[1] *Diagnosis of new genus Belonolaimus:* Tylenchidae closely related to *Dolichodorus* Cobb 1914 but different through the absence of a distinct terminal bulb in the oesophagus and through presence of enlarged oesophageal glands which overlap the anterior intestine; female tail cylindrical, broadly obtuse, annulation following contour of terminus; male bursa not lobed, enveloping tail end. *Type species: Belonolaimus gracilis* n.sp. ♀ Body long, slender, tapering gradually anteriorly, more abruptly posteriorly, annulated; annules laterally interrupted by single groove. Head distinctly set off, four lobed, annulated. Buccal stylet about 157μ long with rounded basal knobs. Procorpus short, containing large ampulla of dorsal oesophageal gland, its outlet near base of stylet; oesophageal canal much folded as stylet is retracted. Middle bulb spherical, with large valves. Isthmus short; end portion of oesophagus consisting of three much enlarged gland cells overlapping the anterior end of the intestine; the latter granular, rather opaque, its cavity obscure; rectum and anus also rather inconspicuous. Female sexual apparatus amphidelphic. Spicula in side view slightly arched, of about same width their entire length, distally pointed; gubernaculum about ⅔ length of spicula; bursa with one short rib representing the phasmid, on each wing near middle of tail.

Measurements: ♀ total length = 2.15mm; α = 52; β = ?; γ = 19.2; vulva = about 52%

♂ total length = 1.7mm; α = 52; β = ?; γ = 14.7

Type location: Ocala, Fla. *Type host:* Slash pine, *Pinus caribaea* Morelet.

WEED HOST PLANTS OF THE NEMATODE FOUND IN THE THREE YEAR TOBACCO ROTATION

H. E. Bratley *

The object of this investigation was to determine which weeds were hosts to the root-knot nematode and the extent of their hospitality. The digging and studying of the roots of all the weeds on each plot would have been too time-consuming and expensive for labor and adequately trained examining crews, so our examinations were spotted throughout each 16 x 77 foot plot. A sufficient number of plants were examined in each plot to give as fair an estimate of the nematode infestations as possible and to cover the area in the month or two allotted to the work.

The plots studied were those used by the Agronomy Department in the three-year, tobacco rotation experiments. Thus this data was accumulated from 222 plots planted to tobacco in 1939 and from 144 plots of the 1940 planting area. The 1939 area was replanted to tobacco in 1942.

During the two consecutive years of weed checking on each of the planting areas the roots of a grand total of 83,627 weeds were observed for knots. Of this total 3,435 plants were found to have knots caused by nematodes. In the spot examinations if a plant was found to be infested the roots of all plants in the immediate neighborhood were examined to determine what other species might be susceptible to nematode attack and the extent of the infestation. The examinations made in 1940-41, or the first two years of the study, included all species of weeds growing on the plots. The last year's examinations were confined to species known to be susceptible to attack from earlier observations on the tobacco plots as well as from other findings.

In 1940, 28,374 plants were examined on the 1939 planting area and 2,841 infested plants were found. The checking of the same area in 1941 resulted in finding 278 plants with knots out of the total of 15,970 examined. Of the 16,989 plants examined on the 1940 planting area in 1941, 77 were found to be infested. In the 1942 examinations of this same planting area 239 plants were found with knots on their roots out of the total of 22,294 examined.

In all, 17 species of plants appeared as hosts to the root knot nematode in the 1940 check of the 1939 tobacco planting area, while 14 species were observed the following year on the same area. The 1941 check of the 1940 planting area showed 7 species infested, while 13 species were found the following year. Thus a total of 25 species of plants were found to be susceptible to nematode attack in the course of this study. In the four checking or examining periods covering three years and two planting areas, three plant species appear four times; 5 species, three times; 7 species, twice; and 10 species, once.

The complete list of host plants is shown in Table I where the total number of individual plants examined for each species also is given; likewise the number of plants infested. The percent of infestation of each plant species through all examining periods gives some idea as to susceptibility.

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TABLE I.—List of Infested Plant Species Occurring in the Tobacco Seedbed Areas of 1939 and 1940 Ranked as to Their Susceptibility to Root-Knot Nematode.

Plant Species	Planting Area				Total Number Plants Examined	Total Plants Infested	Percent Infested
	1939 Year Examined		1940 Year Examined				
	'40	'41	'41	'42			
1. Woolly lupine—*Lupinus villosus* Willd.	91	—	—	—	169	91	53.8
2. Prickly-pear—*Opuntia* spp.	1,240	198	16	70	3,043	1,524	50.0
3. Brazilian mexican-clover—*Richardia brasiliensis* (Moq.) Gomez	1,385	45	53	105	3,202	1,588	49.6
4. Southern pokeberry—*Phytolacca rigida* Small	—	4	1	—	31	5	16.1
5. Cotton weed—*Froelichia floridana* (Nutt.) Moq.	45	1	4	8	838	58	6.9
6. Coastal butterfly-pea—*Centrosema virginianum* (L.) Benth.	1	—	2		103	3	2.9
8. Maypop passion-flower—*Passiflora incarnata* L.	—	—	—	2	71	2	2.8
8. Wormseed goosefoot—*Chenopodium ambrosioides* L.			—	5	337	5	1.5
9. Dollarleaf—*Rhychosia simplicifolia* (Walt.) Wood		5	—	14	1,320	19	1.4
10. Grass-leaf goldaster—*Chrysopsis graminifolia* Michx.		—	—	1	103	1	.9
11. Rough buttonweed—*Diodia teres* Walt.	47	4	1	—	7,381	52	.7
12. Prostrate milkweed—*Asclepias procumbens* L.	4	—	—	—	605	4	.6
13. Milkpea—*Galactia* spp.	6	—	—	1	1,316	7	.5
14. Florida loco—*Astragalus villosus* Michx.	1	—			199	1	.5
15. Partridge pea—*Chamaecrista* spp.	1	6	—	14	6,486	21	.3
16. Dogfennel—*Eupatorium* spp.	47	4	1	—	5,464	15	.3
17. Wild crotalaria *Crotalaria* spp.	1	—		—	268	1	.3
18. Cherokee tickclover—*Desmodium tortuosum* (Sw.) DC.	—	1	—	—	479	1	.2
19. Isopappus—*Aplopappus divaricatus* (Nutt.) A. Gray	4	2	—	9	9,266	15	.2
20. Ragweed—*Ambrosia monophylla* (Walt.) Rydb.	3	—	—	—	1,543	3	.2
21. Risky treadsoftly—*Cnidoscolus stimulosus* (Michx.) A. Gray	2	—		—	1,053	2	.2
22. Fragrant cudweed—*Gnaphalium obtusifolium* L.	—	3	—	1	3,347	4	.2
23. September prairie-clover—*Petalostemon corymbosus* Michx.	—	1	—	2	2,897	3	.1
24. Oakleaf fleabane—*Erigeron quercifolius* Lam.	2	3	—	—	7,860	5	.1
25. False goldaster—*Heterotheca subaxillaris* (Lam.) Britt. and Rusby	1	2	—	2	5,265	5	.1

A total of 62,626 plants of all species, of which an infested member was noted, were examined. This illustrates the enormous possibilities for nematodes to exist and reproduce naturally in such areas, even when not planted to tobacco or any other susceptible crop. It is no surprise, therefore, that the following tobacco crop was attacked by nematodes even though only 4.1% of all of the native plants examined were infested.

Of all the host plants studied, the four most susceptible were: (1) *Lupinus villosus* Willd. (53.8 percent); (2) *Opuntia* spp. (50 percent); (3) *Richardia brasiliensis* (Moq.) Gomez. (49.6 percent) and (4) *Phytolacca rigida* Small. (16.1 percent).

Lupinus villosus was found only on the 1939 planting area the first year of checking. This indicates the ease of exterminating a very potential host of nematodes. The cactus or *Opuntia* spp., with a little care in removing and destroying also could readily be controlled. The *Richardia* or Mexican clover presents a little more difficult problem. There happens to be two species whose aerial growth habits are so similar that identification is difficult. The root growth, however, is very distinctive. *Richardia brasiliensis*, a perennial, has a fleshy root while *R. scabra* has a more or less fibrous root system. The surest method of handling these species would be to gather and destroy them. The fleshy root of pokeberry suggests another plant which would have to be gathered and removed to be sure of control. In checking operations the plants were allowed to remain on the plots upon which they were growing. Cactus, Mexican clover and pokeberry in many instances reattached themselves to the soil and so were a continued source of reinfestation by the nematode.

Isopappus divericatus (Nutt.) T. & G., another member of the host list, was the most abundant species found on any of the areas. Fifteen members were found infested in the 9,266 plants examined. Examination of large fleabane, *Erigeron quercifolius* Lam., the second most abundant species, resulted in the finding of 5 infested plants among the 7,860 examined.

In preparing a percentage table for each period of examination on each of the planting areas 6 to 9 of the more commonly infested plants were used. The table was provided with 7 columns headed: NK, no knots; VL, very light; L, light; M, medium; H, heavy; VH, very heavy; and total infestation. Upon examination, the plants were placed in one of the first six columns. The NK representing no knots received a tally when a specimen was found to have no deformities of its roots due to root-knot nematodes. The next 5 columns were used to check plants having nematode knots on their roots to varying degrees. Which of the five received the tally was determined by the examiner and is not, of course, an exact value. In other words a more or less sliding scale upon which to fix a determination was used. What may seem a medium infestation to one person may be to another a heavy infestation and likewise for the other gradations of infestations. The last column is the total, determined by the sum of the numbers contained in the columns showing degree of infestation. The percentages were used to give a comparative value to the infested plants and thus provide a better picture of the whole situation. While this table shows many interesting relationships it will not be published until a later date.

NATURAL CONTROL OF ROOT KNOT

J. R. Watson *

It may seem a far cry from insects down to nematodes but they are certainly more closely related to insects than they are to fungi, though much of the work on nematodes has been done by plant pathologists. We entomologists are called upon to give advice on anything from mammals to protozoa, including especially spiders and spider mites. Because of the importance of the subject in Florida it occurred to me that an account of our recent work at the Station on nematode control might be of interest to you.

For several years we have been investigating the use of mulches on such plants as figs, peaches, roses, and other shrubs where the application of soil sterilization by chemicals was out of the question. It has long been recognized that figs, for instance, do better when planted up against a building under which the roots could run. This may not be entirely due to their escape from nematodes by rooting in the dry soil under the building, but perhaps due in part to the lower temperatures in the soils there: at least this was the opinion of Dr. P. H. Rolfs. During the last few years we have extended this work considerably by trying out different materials for the mulch as well as different thicknesses, and lately have been attempting to determine possible causes of the control of nematodes under these mulches.

During the last couple of years we have had marked success in mulching okra, peas, lettuce and even comparatively tall annuals. During the past year we have been trying a series of greenhouse pot experiments in which we have watered tomatoes and okra with an extract made by soaking this mulching material in water. Though the plants have not grown as well as under the mulch they have done very much better than those plants in check pots. From none of the latter did we get any fruit. They all died before producing any. It is recognized that this extract might have considerable plant food in it but it is difficult to determine just how much. Consequently, we gave all the pots what we considered an abundance of fertilizer so we feel that the difference in growth in our pots watered with the extract is not primarily due to any extra fertilizer.

In cooperation with the Department of Soils of the Agricultural College, we are making a study of the biota, particularly the fungi under these mulches as compared with that in the check plots. The most striking difference is in the abundance of species of *Trichoderma* and *Penicillium* under the mulches. A worker at the Pineapple Experiment Station in Hawaii has come to the conclusion that controlling nematodes under the mulch is due to fungi and another worker claims that he has actually seen the fungi penetrating the worms and, of course, killing them. In our attempt to see if the material used for the mulch is of any practical importance we have used on different plots, grass, weeds, crotalaria

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stems, leaves from the forest, and hyacinths from a lake. We can see no difference in these different materials. Practically any vegetable matter that will decay seems to be suitable.

In our experiments regarding the depth of the mulch, our first guess was that the deeper the mulch the better, and this is certainly true from the standpoint of holding down weed growth and conserving moisture. However, the results of the past year seem to indicate that an inch or two of mulch gives nearly, if not just as good nematode control as greater depths. Indeed, the control seemed to persist for nearly a year after the coarse mulch on top of the plots was removed. To be sure there was considerable organic matter still left in the soil. It seems to make no difference whether the organic material was piled on top of the ground or incorporated in the soil. Paper, however, did not give control, indicating that it is not alone the shading of the ground or conserving of moisture which controls nematodes, but the decaying of organic matter. Of course, we do not get complete eradication of the nematodes by this method. As in other instances of biological control, we cannot expect to get every last nematode, but it does enable us to get a fairly good crop of very sensitive plants like okra in very heavily infested soil. In all our nematode work our aim has been control rather than eradication. The organisms are so widespread in all sandy soils in Florida and so easily introduced that reinfestation would be fairly prompt even where a complete eradication has been achieved.

In the case of seed beds, of course, we do want as complete control as possible. This is best and most thoroughly achieved by steaming the soil. Unless the seed bed or greenhouse is permanently piped so that steam can be quickly and economically turned on, this method has proven expensive. Both the pan method, the hollow-toothed harrow method, and also the hot water method have proven more expensive than has ours through fumigation with hydrocyanic acid gas generated in the soil by first treating with a solution of cyanide and then ammonium sulfate. When the large amount of fertilizer left in the soil by this method is taken into consideration, this is by all means the cheapest procedure we know of for completely eradicating nematodes. Dr. Hinds of the Alabama Station recently told me that he considered the fertilizer value of the material alone as equal to the cost and thus he got the eradication for nothing. However, the expense of this method is too high except for seed beds, back yard gardens, and other especially valuable areas.

Under natural control we might perhaps include the starvation method such as growing crotalaria or velvet beans on the land in the absence of all other plants, but it is to the results of mulching that I particularly wish to call your attention at this time. When one considers how lacking our Florida soils are in organic material and how important the conservation of our water and soil resources and the control of nematodes are to our national future, the burning of refuse as is commonly done in cities and even on some farms is little less than a treasonable crime, except of course in the case of plant materials dangerously infested with some plant disease or insect.

PRELIMINARY OBSERVATIONS ON THE USE OF DICHLOROETHYL ETHER IN THE CONTROL OF NEMATODES

Ralph L. Miller *

Dichloroethyl ether is a colorless, clear liquid with a pungent odor. It has a specific gravity of 1.22 and boils at 178° C. It is very slightly soluble in water, but soluble in most organic solvents.

During the past six years considerable experimental work has been done with this product in various combinations and under many different conditions so that its toxicity to many insects and the tolerance of many plants to it have been fairly well established. As a background for work in Florida, several satisfactory uses for dichloroethyl ether are mentioned below.

In 1940 B. B. Pepper reported in Vol. 33, No. 2, of the Journal of Economic Entomology that a four year summary of the use of dichloroethyl ether against wireworms attacking cruciferous crops had shown that 0.8 to 3 ounces per gallon, used at the rate of one-third to one-half pint per plant, gave 99 to 100 per cent control of wireworms. He also reported that this concentration killed larvae and pupae of the cabbage maggot, the larvae of the Japanese beetle, as well as earthworms and centipedes. He further stated that it was safe on cabbage, cauliflower, kale, broccoli, beans, Swiss chard, and horseradish; and, in some instances, seemed to have a stimulating effect on the growth of these crops. Tomatoes and cucumbers, however, were found to be sensitive to large doses, but were improved by small amounts.

In 1942 Roy E. Campbell, also working with wireworms, reported in Vol. 35, No. 1, Journal of Economic Entomology, that one-third ounce per gallon, used at the rate of one quart per hill, reduced wireworm so that four to five times as many watermelon plants grew per hill. Dr. Campbell also reported that larger amounts or higher concentrations were toxic to watermelons. He reported, too, the use of dichloroethyl ether as a dust but the proper amount and concentration were not completely worked out.

In 1942 P. O. Ritcher and H. H. Jewett reported in the Journal of Economic Entomology, Vol. 35, No. 3, that 2.3 ounces of dichloroethyl ether in two gallons of water, applied per square yard, gave 85 per cent kill or control of white grubs, while 2.7 ounces in two gallons of water, applied per square yard, gave 96 per cent kill or control. In 1942 O. I. Snapp, in Circular E-558, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, reported a 100 per cent kill of plum curculio larvae and almost complete kill of pupae in soils sprayed with one ounce of dichloroethyl ether per gallon of water and used at the rate of one-sixth gallon per square yard.

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In 1940 S. C. Jones, in the Journal of Economic Entomology, Vol. 33, No. 4, reported that one-third ounce of dichloroethyl ether per gallon of water was applied to one square yard of soil and complete kill of pear thrips in the soil resulted.

Another insecticidal use of dichloroethyl ether, as reported by B. B. Pepper, in 1940, is the application of one cc. or one-fourth teaspoon of a 1 to 5 per cent solution in heavy mineral oil, applied to corn silks, to destroy corn earworm. It was found by Mr. Pepper that two to three per cent of dichloroethyl ether in heavy mineral oil, applied to corn silks, gave 95 to 96 per cent corn earworm free ears, with no injury to the corn. Larger amounts or higher concentrations injured the corn slightly.

The writer has not attempted to make a complete survey of all the literature published on the use of dichloroethyl ether, but has mentioned the above papers only as a background for its use in Florida.

C. B. Wisecup, of the U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, at Plant City, was probably the first in Florida to use dichloroethyl ether for soil fumigation. Mr. Wisecup reported that concentrations of approximately one ounce of this chemical per gallon of water, applied at the rate of two gallons per square yard, killed and prevented reinfestation of mole crickets for approximately three months in soil in which a barrier had been constructed, so as to prevent reinfestation from outside, untreated soil. In this preliminary report, given in December 1942, to the Florida Entomological Society, in Orlando, Mr. Wisecup reported, however, that where no barrier was used to prevent reinfestation from the mole cricket population in the adjoining untreated plot, within a week to ten days the treated soil had become reinfested.

During the summer of 1942, the writer treated a small area in a flower bed, heavily infested with root knot nematodes, with dichloroethyl ether at the rate of one ounce per gallon of water, and two gallons of this concentration per square yard. The soil was sandy and comparatively loose so that penetration resulted to six or eight inches. Immediately after the treatment, okra seed were planted the entire length of the bed, directly through the part treated with dichloroethyl ether. Germination was not affected since as many plants were present in the treated area as in the untreated. All plants began growth normally, but within a short time the okra plants growing in the untreated soil began to appear stunted and grew quite slowly, while those in the dichloroethyl ether treated soil grew rapidly and became quite large. (See Fig. 1.) At the end of the season, the roots of the plants were carefully taken out of the soil and it was found that the roots of the okra plants growing in the untreated soil were completely knotted and small, while those growing in the area treated with dichloroethyl ether had no root knot deformities visible on the roots.

Many types of emulsifiers have been tried for making a more uniform and complete mixture or emulsion of dichloroethyl ether in water. In the above experiment, however, a small amount of dichloroethyl ether was placed in the bottom of a sprinkling pot and the force of the water in filling the container was sufficient to make a fairly good temporary emulsion that remained comparatively uniform while the application was

being made by means of the same vessel. It is the writer's suggestion that, for preliminary testing of this chemical it be used at the rate of one ounce (liquid measure) per gallon with two gallons of the diluted mixture per square yard. Although no damage apparently results from the treatment of soil with dichloroethyl ether and planting immediately, some plants or young seedlings apparently developed somewhat better if a space of four to five days between treatment and planting or setting is allowed to elapse.

Although considerable work needs to be done with dichloroethyl ether to determine all of its possibilities as a soil fumigant and insecticide, it has many distinct advantages for use in this connection.

In the first place, it can be applied directly to growing plants, which is a considerable advantage over most other soil fumigants. It can be applied with a sprinkling pot over the tops of growing plants, and allowed to soak into the soil, where this is necessary, provided the chemical is carefully washed off the tops of the plants. In loose, sandy soil, the concentrations suggested above apparently are very effective against most of the hostile soil-inhabiting organisms in Florida and it is the writer's opinion that it is well worth testing to a considerable extent.

Figure 1.—Okra plants treated with 2 ounces of dichloroethyl ether in two gallons of water applied per square yard, left, and untreated, right. Note poor growth of untreated plant, right, above, and the severely deformed condition of its root system, below.

CHEMICAL CONTROL OF PLANT PARASITIC NEMATODES IN THE SOIL

A. L. Taylor *

The purpose of this paper is to summarize the information now available on control, by chemical treatment of the soil, of those nematodes that cause plant diseases. Much of the material is derived from the experiments carried on by the author and his co-workers at the Coastal Plain Experiment Station, Tifton, Georgia, during the past several years, but a large amount of data has also been obtained from publications of other workers in this field.**

WHEN CHEMICAL TREATMENTS ARE DESIRABLE

Chemical treatment of the soil should be considered by the grower when nematodes are found to be attacking his crops to such an extent that there is danger of serious economic loss. The amount of nematode damage can be determined only by careful examination. The characteristic knots formed by the most common plant-infecting species, the root knot nematode, on such crops as tobacco, beans, celery, peas, squash, melons, cucumbers, figs, tomatoes, papayas and many other crops are probably familiar to most Florida growers, and the generally unthrifty growth of attacked plants has often been observed. But Florida soils also have been found to contain other plant parasitic nematodes. Some of the most important belong to the meadow nematode group. These parasites also invade roots, but do not stimulate gall formation. Instead, they move through the root, destroying cells and feeding on the contents as they go. The lesions so created provide entrance for secondary invaders, fungi and bacteria, which extend the damage started by the nematodes. The final result is the partial or total destruction of the root system. Still other nematodes invade the stems and leaves of plants. As the damage produced by these parasites closely resembles that caused by other plant pests, the true cause is often not recognized.

In case there is any doubt as to whether nematodes are causing an appreciable amount of damage, the grower should apply to the Division of Nematology, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Department of Agriculture, Washington, D. C., or Tifton, Georgia, forwarding samples of attacked plants and a small sample of soil from immediately around the roots of the plants.

Chemical control is practical only in those special cases where the rather large cost will be more than balanced by the market value of the increased yield. It is not intended to replace such control measures as rotation with non-susceptible crops, fallowing and trap cropping. Chem-

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** The bibliography at the end of the paper is not intended to be complete. Only the recent or readily accessible papers are listed.

icals can replace steam sterilization of soils to a certain extent and can be used where facilities for steam sterilization are not available. Where the grower has a large investment in greenhouses, lath houses or shades, the cost of chemical treatment of the soil will usually be far less than the expense of replacing the soil or moving the installation to a new position.

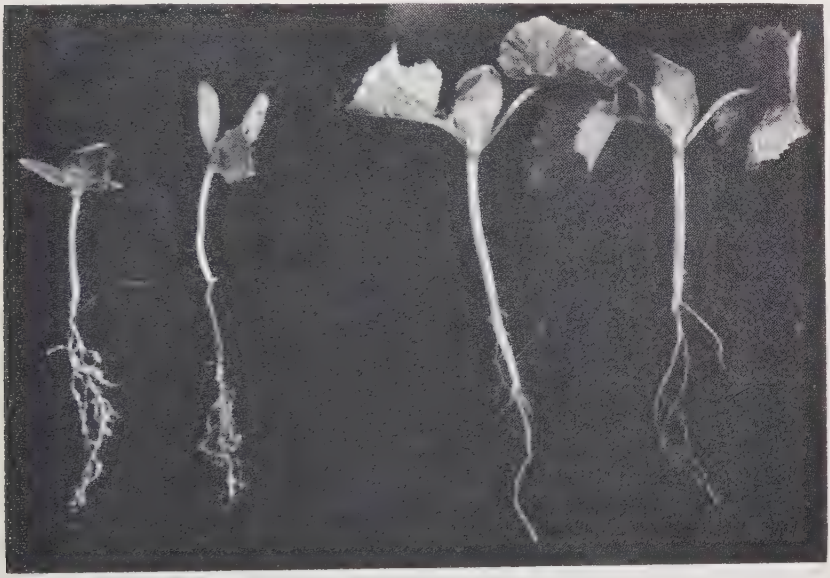

Figure 1.—Root knot on cucumber seedlings. The four plants are from the same short row. The two on the left were heavily attacked by root-knot nematodes. The two on the right escaped infection. Note the characteristic knots on the attacked plants and the difference in size.

MATERIALS AND METHODS

To be useful for soil treatment, a chemical must be very deadly to nematodes. As the soil is to be planted after treatment, it must not leave any residue harmful to plants in the soil. To be practical, it must be fairly easy to apply and not too dangerous to man. Finally, it must not be too expensive.

In order to kill nematodes, the chemical must be brought into contact with them. That is to say, it must be distributed through the upper 18 inches or two feet of soil in the field. Obviously, it is easier to distribute a gas through the soil than either a liquid or a solid. On the other hand, gases are not easy to confine and measure. This difficulty can be eliminated by the use of liquids or solids that evaporate or decompose in the soil to form fumes or gases.

Poisons may also be dissolved in water and the solution used to saturate the soil. In practice, this method has not been very successful as diffusion of the liquid, especially into the deeper portions of the soil, is very slow.

Use of insoluble or nearly insoluble solids in powder form is limited by the mechanical difficulty of thorough mixing with the soil.

At least 200 chemicals have been tested in this country and abroad for nematode control, but only a few have been found to have the desired properties. These will be discussed below. So far as the author knows, no substances except those mentioned have been proven to be of practical value for control of nematodes.

Figure 2.—Goldenrod from a commercial planting in Florida. Meadow nematodes destroy root cells, produce lesions as shown by arrows, and seriously weaken the root system.

Exhaustive tests by scientific workers and experience based on extended commercial applications have demonstrated that nematodes can be controlled by use of chloropicrin. Other chemicals known to be effective are carbon bisulphide, ethylene dichloride, methyl bromide and methyl bromide mixtures. All of these are liquids except methyl bromide,

which is a gas at temperatures above 40° F. and at atmospheric pressure. Hydrocyanic acid gas produced by a reaction between sodium cyanide and ammonium sulphate has also been highly recommended. Cyanamid has been extensively tested with variable results. Urea has recently been reported to be effective in controlling root knot in tobacco seedbeds. In one case, dichloroethyl ether was reported to have produced excellent results when applied to soil containing growing plants.

CHLOROPICRIN

Chloropicrin is a colorless or slightly yellow liquid about 1.6 times as heavy as water. It evaporates readily to form a pungent gas several times heavier than air. The gas is highly irritating to the eyes, and to the mucous membranes of the throat and lungs. Small concentrations in the air cause profuse watering of the eyes. Larger concentrations cause violent coughing and vomiting. Very heavy concentrations may even be lethal. However, it is not particularly dangerous to use because the smarting of the eyes is a warning that will never be disregarded by even the most careless workman. No one will voluntarily stay in air containing even a small fraction of the lethal concentration. Smarting of the eyes, coughing and vomiting are temporary symptoms which disappear soon after the victim gets into fresh air. With proper precautions and special applicators, it can be used without even temporary inconvenience. It is not inflammable.

Chloropicrin is applied after the soil has been prepared for planting, but several days before the crop is actually planted. This is necessary because it is also poisonous to plants and time must be allowed for it to diffuse out of the soil. Usually the soil is plowed, harrowed, if necessary to break up clods and then carefully leveled. The surface is then marked for placing the applications by scratching lines lengthwise and across with a row marker. The operator then proceeds along the lengthwise set of lines with the applicator set to deliver the proper amount of chemical at a depth of four to six inches. The most convenient method is to work two lines of application points at once, placing the applications at the intersection of the marked lines in one row and halfway between the intersections of the lines in the other row. The result is two staggered rows of applications. This is repeated until the area to be treated is covered. After treatment the soil is immediately raked smooth and either covered with a gas impervious cover or sprinkled with enough water to wet the top inch or two. The purpose of the cover or water seal is to prevent too rapid escape of the fumes from the soil, and thus to make the most efficient use of the chemical. This is a highly important part of the procedure and should never be omitted. The water seal is as efficient as the gas tight cover and is usually more convenient. Our usual practice is to sprinkle with water until it no longer soaks in instantly and to renew the water seal once or twice at intervals of two hours or so, depending on the rate of evaporation. This completes the treatment and the crop can be planted as soon as the soil is free of the odor of chloropicrin, usually five to seven days after treatment. A test can be made by digging up an handful of treated soil from a depth of six

or eight inches and smelling it. If several samples from various points in the plot are free of the odor of chloropicrin, it is safe to plant.

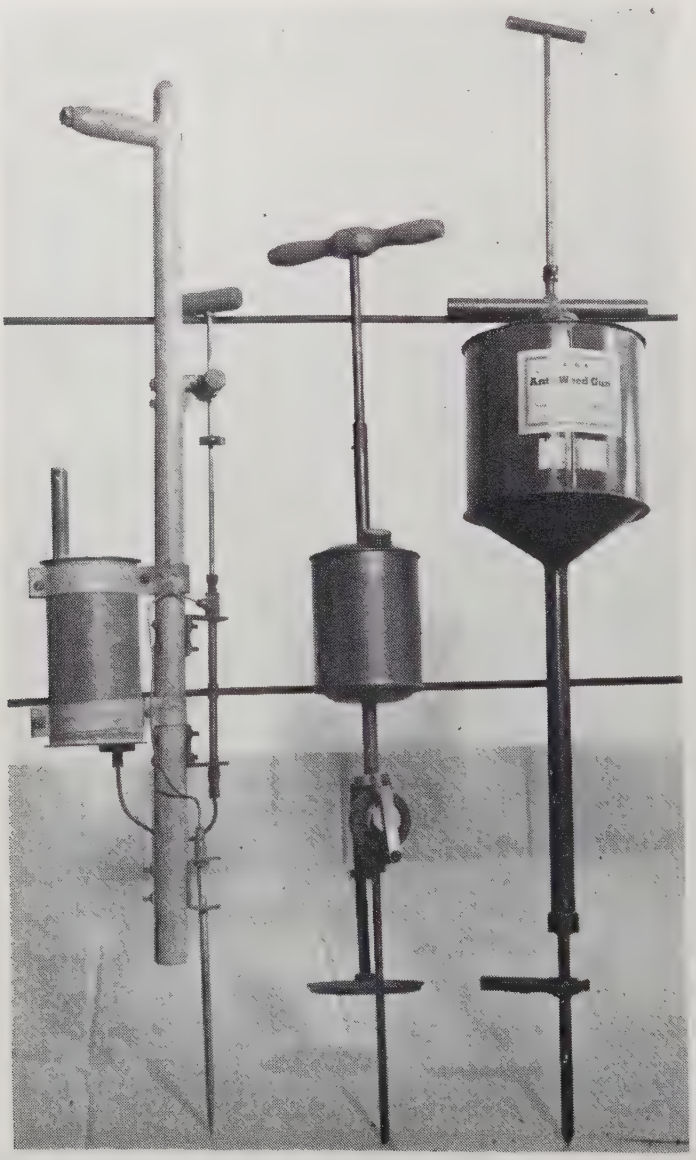

Figure 3.—Soil fumigant applicators. Left: Applicator designed by the Division of Nematology, U. S. Dept. of Agriculture. (Public patent No. 2,177,792. Oct. 31, 1939.) Center: Commercial applicator designed for use with chloropicrin. Right: Commercial applicator for use with carbon bisulphide. All these applicators discharge through a small hole near the bottom of the spike.

Chloropicrin should not be applied to the soil when it is either too dry or too wet. Either condition will make the application ineffective. In our sand loam soil, best results have been obtained with a soil moisture content of 6% to 8%. At this moisture content, the soil is just wet enough so that it will hold its shape when moulded in the hand. Soil temperature, at least within the range found in Florida under normal field conditions, seems to have little bearing on the efficiency of the fumigation. In other sections of the country, applications are not made when the soil temperature is below 50° F.

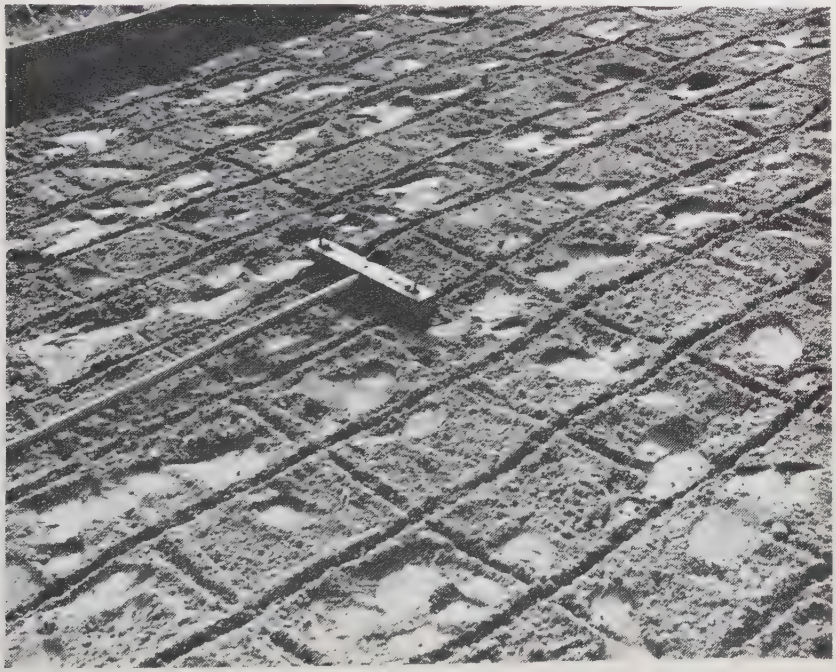

Figure 4.—A plot marked for soil fumigant application.

In the sandy loam soil at Tifton, excellent results are usually obtained with applications of 1.5 cc of chloropicrin spaced at 14-inch intervals. Other workers have found that closer spacing and larger applications are sometimes necessary. Amounts range from 2 cc to 4 cc and spacing from 10 to 12 inches. Apparently the character of the soil influences the effect of the chemical and the most economical application rate and spacing can be determined for any given location only by trial. Good results are nearly always obtained with applications of 2 cc or 3 cc and 12-inch spacing. This combination might be used as a basis for experimental work or for treatments where there is no time for experiments.

Applications of chloropicrin at the rates mentioned require from 200 to 400 pounds of the chemical per acre. Total cost, including ap-

plication would be $3.70 to $7.40 per 100 sq. yds. or $180 to $360 per acre.

One man with a hand applicator can treat about 1000 square feet per hour. Several machines have been designed for large scale applications, but none has been placed on the market.

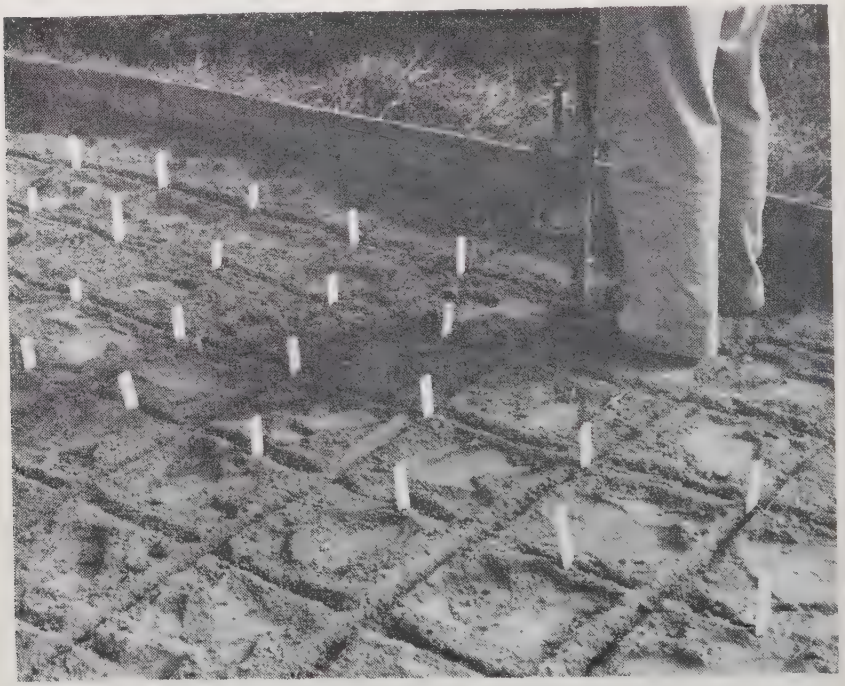

Figure 5.—Applying soil fumigant to a marked plot. The operator has just placed one application. The markers show where other applications will be placed. Note that the applications are placed in staggered rows, at the intersections of the marked lines in one row and halfway between the intersections in the next row. (The markers are not used in ordinary work, but are included here to indicate the proper placing of the applications.)

CARBON BISULPHIDE

Carbon bisulphide is a colorless or slightly yellow liquid with a characteristic rotten egg odor. It has been shown to be very effective for control of root knot nematodes when applied in the same manner as described for chloropicrin. On sandy loam soil at Tifton good control was obtained by applications of 5 cc to 10 cc spaced at 14-inch intervals. This is about 500 to 1000 pounds per acre. At the present market price of 5¢ per lb. in 55 gallon drums, total cost of a carbon bisulphide application is about $.93 to $1.86 per 100 sq. yds. or $45 to $90 per acre.

The great disadvantage of carbon bisulphide is that it is highly inflammable and the vapors form an explosive mixture with air. Its use in fumigation of stored grain for insect control has resulted in several

serious accidents. It must be handled with extreme care. In addition the vapors are poisonous, especially on prolonged exposure. In the opinion of the author, these factors outweigh its decreased cost.

Emulsions containing 68% of carbon bisulphide have also shown some value as soil nemacides. They are mixed with enough water to saturate the soil and applied by simply pouring into furrows which are then covered. In experiments at Tifton, about five times as much carbon bisulphide was required for good control of root knot when used as an emulsion as when used unmixed.

Figure 6.—Applying the water seal. A portion of the plot has been treated and raked smooth. Enough water is applied to wet the top inch or two of soil. The purpose is to prevent too rapid escape of the chemical fumes from the soil. This completes the fumigation.

ETHYLENE DICHLORIDE

Ethylene dichloride has been shown to be a fair soil nemacide when properly applied. It is a colorless liquid with a not unpleasant odor. It is somewhat inflammable, but not as much as carbon bisulphide. The vapors are slightly poisonous and prolonged breathing of them should be avoided.

Good control of root knot nematodes was obtained at Tifton with 10 cc applications spaced at 7-inch intervals, or about 4000 pounds per acre. Application procedure is the same as for chloropicrin except for the closer spacing of the applications.

Present market price of ethylene dichloride is about 7¢ per pound in 55 gallon drums. Cost of the effective application is $5.60 to $7.40 per 100 sq. yds. or $320 to $360 per acre.

Mixtures of 9 parts of ethylene dichloride and one part of chloropicrin have been shown to be very effective against the root knot nematode and the bulb and stem nematode in experiments in New York State. Applications of 10 cc were spaced at 10.5-inch intervals. Cost is about $300 per acre for the chemical alone. The mixture has the advantages of being easier to handle than chloropicrin and not so laborious to apply as ethylene dichloride.

METHYL BROMIDE

Methyl bromide has been shown to be a very efficient soil nemacide in experiments at Tifton. It has been used in two forms, as pure methyl bromide and as a mixture of 10% methyl bromide with other chemicals. One mixture, originated for use as an insecticide, contains 10% methyl bromide, 67.5% ethylene dichloride and 22.5% carbon tetrachloride. This mixture is applied to the soil in much the same way as chloropicrin. Preliminary experiments have indicated that good control of root knot can be obtained by the use of 5 cc applications spaced at 14-inch intervals or 2.5 cc applications spaced at 10.5-inch intervals. This is about 500 pounds per acre in either case and the cost, including application, would be about $2.07 to $2.48 per 100 sq. yds. or $100 to $120 per acre.

If subsequent work confirms the results of these experiments, methyl bromide mixture will be of considerable value as soil nemacides. The mixture is a colorless liquid which burns with some difficulty. The ethylene dichloride is inflammable, but both methyl bromide and carbon tetrachloride are used in fire extinguishers. Methyl bromide mixtures are not unpleasant to handle nor particularly poisonous, if prolonged breathing of the vapor is avoided.

Pure methyl bromide has a boiling point of 40° F. and is a gas at temperatures above this point. For soil fumigation, it is applied under a gas tight cover over the soil to be treated. The cover is placed over the plot with is edges buried in a shallow ditch. The methyl bromide is then introduced into the space between the cover and soil surface by means of a special applicator. The cover is left in place for a day or two, then removed and another day is allowed for the soil to aerate before the crop is planted. Cover may be glue coated kraft paper or gas impervious tarpaulin. This method is of value for small plot only, such as greenhouse beds and bench. Excellent results have been obtained with applications of one cubic centimeter of methyl bromide per square foot. Cost of the chemical alone is about $3.00 per 100 sq. yds.

SODIUM CYANIDE AND AMMONIUM SULPHATE

It has been reported that excellent control of root knot in Florida soils can be obtained by the use of hydrocyanic acid gas generated by a reaction between sodium cyanide and ammonium sulphate. The sodium cyanide is dissolved in water and poured over the soil. It is followed immediately by the ammonium sulphate, also in water solution. Amounts recommended are: 300 pounds of sodium cyanide per acre on very sandy soils; 600 to 1000 pounds per acre on medium light sandy soils; and 1200 to 1500 pounds per acre on heavier soils. In each case, one

and one-half times as much ammonium sulphate as sodium cyanide is used. The crop may be planted one week after treating. Cost of the treatment is estimated at $1.10 to $5.50 per 100 sq. yds. or $52.00 to $260.00 per acre for the chemicals alone, but some of this may be charged to fertilizer cost as the treatment leaves the soil immensely rich in nitrogen.

Extreme caution is necessary in using this method as both the sodium cyanide and the hydrocyanic acid gas generated by the mixture are deadly poisons. In applying the chemicals, the worker should always keep to the windward side of the application and should wear a gas mask with a canister approved for use with hydrocyanic acid gas. The sodium cyanide solution should not be touched with the hands and the hands should be washed thoroughly before eating. The treatment must not be used near dwellings which are occupied while the work is in progress or for several hours afterward. The fumes will kill all living plants in the treated plots and may injure those in the near vicinity.

CYANAMID AND UREA

Cyanamid, in powder form, is generally sold as a fertilizer and has often been recommended for control of nematodes. While it has been reported as giving good results in some places, experimental applications at Tifton failed to produce any appreciable effect on the nematode population of the soil even with applications of 4000 pounds per acre.

Urea has recently been reported as being effective for control of root knot in tobacco seedbeds when used at the rate of one pound per square yard, spaded in to a depth of 4 inches. The chemical was applied in the fall and the tobacco seed planted in the early spring. Until further details are available, the use of urea is not recommended except in experimental work.

DICHLOROETHYL ETHER

A Florida grower has noted increased growth of plants and apparent freedom from nematode damage on soil treated with a solution of dichloroethyl ether in water. The chemical is mixed with water in a sprinkling can, poured on the soil around the roots of growing plants and washed into the soil by further applications of water. Exact information is not available, but it is probable that about 12 cc of the chemical is used per gallon of water and the solution used at the rate of two to four quarts per square foot. This amount of dichloroethyl ether will dissolve in water. Until further tests are made, this method is recommended only for experimental use. If the results apparently obtained are verified, this chemical will be an extremely valuable addition the technique of nematode control, for it will be the only method by which soil treatments can be made after the crop is planted. Experiments at Tifton in which the dichloroethyl ether was applied to the soil in the same manner as described above for chloropicrin, indicated that the chemical was not particularly effective against root knot. A residue remained in the soil for at least eleven weeks after treatment and there

was some apparent damage to the indicator crop used to determine the remaining nematode infestation. It should be noted that the dichloroethyl ether was not applied in water solution in this case.

TOBACCO DUST WITH BARIUM COMPOUNDS

A commercial preparation consisting principally of tobacco dust and phosphate rock with small amounts of barium sulphide and barium carbonate has been extensively sold for root knot control in Florida. According to the label on a bag obtained in 1942, it contains 2% nitrogen, 6% insoluble phosphoric acid and 3% potash. In experiments at Tifton, this preparation failed to produce any appreciable effect on the root knot nematode population even when used at 27 pounds per 100 square feet, or more than twice the recommended rate.

FERTILIZERS

There is considerable evidence to indicate that increased yields can sometimes be obtaind by heavy fertilizer application to nematode infested crops. Since the nematodes interfere with root growth, anything which will stimulate roots will counteract the damage to some extent. Potassium, phosphorus and nitrogen are most often mentioned in this connection, but the Florida grower should also be on the watch for deficiencies in minor elements. Frequent cultivation and a plentiful supply of water will also help.

SPOT AND ROW TREATMENTS

To reduce the cost of large scale applications of chemicals, the spot treatment technique was devised. As only a small portion of the area of a field is occupied by the roots of such crops as watermelons planted in hills, and as the root knot nematode can move through the soil at the rate of only about a foot a month, it is evident that the whole area of the field does not need to be fumigated. Plants grown in the middle of a small treated area of soil will escape attack for a greater or lesser time, and certainly will not be attacked in the early stages of growth, when even a light infection can do a large amount of damage.

In practice, the field is prepared for planting and the planting spots are plainly marked. An injection of two or three cubic centimeters of chloropicrin is made at each planting spot about six inches beneath the soil surface. A water seal is formed by sprinkling an area of about one square yard around the planting spot. One week later the seed is planted. Experiments with this system reduced root knot of watermelons from an average of 90% on the untreated controls to less than 5% on the treated spots, when tested in the early stages of growth. At harvest, more than 90% of the treated hills were free of root knot and the remainder were only lightly infested, while nearly all of the untreated hills were heavily infested.

Cost of spot treatments ranges from $5 to $10 per acre for watermelons planted in hills 8 feet apart, to $30 to $40 for tomatoes planted 3 feet apart.

A logical extension of this method for the planting of row crops, is to so place the chemicals that continuous rows of nematode-free soil are available. In a preliminary experiment, applications spaced 14 inches apart were made in two staggered rows 12 inches apart, and the crop was placed in the middle of the treated area. Fairly satisfactory control of root knot was obtained with both 2 cc applications of chloropicrin and 10 cc applications of methyl bromide mixtures.

Cost of row treatment with either chemical is about one dollar per 100 feet of row.

DISCUSSION

If properly done, chemical treatment will reduce the nematode population of the soil to the point where the grower can expect that at least 95% of the first subsequent crop will escape serious damage.

It is apparently impractical, because of cost, to eliminate the nematodes entirely. A few will always escape and the population will eventually increast to its original level. For purposes of calculating costs, the grower should not count on more than one crop before the treatment will have to be repeated.

In addition to nematode control, some of the chemicals, such as chloropicrin, will also give some protection against soil-borne diseases caused by fungi and bacteria. Nearly all the chemicals will destroy some insects in the soil.

In calculating the cost of chemical treatment, one Florida grower of a specialty crop for sale to florists reduced the cost item to a crop unit basis. He found that he was growing about 40,000 plants to the acre. Cost of chemical treatment estimated at $400 per acre would be about one cent per plant. Increase in size, quality and number of marketable plants per acre more than paid for the cost of the treatment.

The decision to use or not use chemicals involves a mathematical problem each grower must solve for himself. The variables are the number of crop units per acre, the market price of the crop and the increase in yield and quality of plants grown on clean soil compared with yield and quality of plants from infested soil. In a nursery, for instance, even a light infestation with the root knot nematode might cause the rejection of stock for transplanting. The possibility of spot or row treatments should always be considered. Even where it would not pay to use chemicals in the field, the grower will often find their use advantageous in the seedbed.

A careful campaign to prevent reinfestation of the soil should always accompany the use of chemicals. As noted above, nematodes move about only very slowly by their own efforts. But they can easily be carried from place to place by running water, or in mud on the feet of men and animals and on cultivating implements. Serious trouble can usually be avoided by cleaning feet and tools when going from untreated soil to treated soil, especially in wet weather. Scraping off clinging soil will remove most of the nematodes, and scraping followed by washing will remove nearly all of them. Nematodes are often introduced into the soil by transplanting infected material, either in the roots of the plants or in soil clinging to the roots.

SUMMARY

Nematodes injurious to plants can be controlled by the use of chemicals. Such treatment should be considered when the grower finds that the economic loss caused by the nematodes will be balanced, or more than balanced, by the cost of treatment.

Chemicals which have been proven to be of practical value for this purpose, their approximate cost per acre and per 100 square yards, including labor of application, advantages and disadvantages, are summarized as follows:

Chloropicrin costs $180 to $360 per acre ($3.70 to $7.40 per 100 sq. yds.). This chemical has been proven in commercial applications and information concerning it is readily available. It is disagreeable but not dangerous to handle.

Carbon bisulphide costs from $45 to $90 per acre ($.93 to $1.86 per 100 sq. yds.). It is not as unpleasant to handle as chloropicrin, but is much more dangerous, as the liquid is inflammable, the vapors explosive when mixed with air, and the fumes poisonous. Carbon bisulphide emulsion is inefficient.

Ethylene dichloride costs from $320 to $360 per acre ($5.60 to $7.40 per 100 sq. yds.). It is easier to handle than chloropicrin, but about 20 times as much is required to treat an equal area. It is slightly inflammable, but not as much as carbon bisulphide. More labor is required for application than with chloropicrin. Mixtures of ethylene dichloride and chloropicrin have been shown to be effective. Advantage of the mixture is that it is easier to handle than chloropicrin and not as laborious to apply as ethylene dichloride. Cost is about $300 per acre for the chemical alone.

Preliminary experiments have indicated that good control of root knot and other nematodes can be obtained with methyl bromide mixtures (10% methyl bromide) at a cost of $100 to $120 per acre ($2.07 to $2.48 per 100 sq. yds.). Methyl bromide mixtures are easy and not particularly dangerous to handle. Unqualified recommendations cannot be made until further experimental data are accumulated. Pure methyl bromide has limited value for small scale work.

Hydrocyanic acid gas formed by a reaction between sodium cyanide and ammonium sulphate is reported to be effective. Cost is estimated at $52 to $260 per acre for the chemicals alone ($1.10 to $5.50 per 100 sq. yds.) Extreme caution must be used with these chemicals as sodium cyanide and hydrocyanic acid gas are deadly poisons.

Cyanamid appears to be erratic in action. Application of 4000 pounds per acre failed to control root knot at Tifton, Georgia.

Urea has been reported to be an effective nemacide for use in tobacco seedbeds. It cannot be recommended until further data are available.

Dichloroethyl ether has been reported by a Florida grower to give good control of the meadow nematode. It is applied to the soil in water solution after the crop is planted. If further tests confirm this report, it will be a valuable addition to the list of chemicals available.

A commercial preparation of tobacco dust, phosphate rock and barium compounds failed to produce any appreciable effect on the root knot nematode population of soil at Tifton, Georgia.

Some benefit from the standpoint of crop yields can be obtained by heavy fertilizer applications for nematode infested plants.

Spot and row treatments can be used for control of nematodes on crops planted in widely spaced rows or hills, with considerable saving in the amount of chemical required.

Chemical treatment of soil is a practical proposition only where the prospect of increased crop yields will more than balance the extra expense.

Chemical treatments should always be accompanied by a careful campaign to prevent reinfestation of the soil by running water, by soil carried in from infested areas and by infected plants.

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THE CONTROL OF NEMATODES IN THE ORGANIC SOILS OF THE EVERGLADES

G. R. Townsend *

Growers who have seen the devastating effects of a nematode infestation may think the problem is without a solution. However, nematodes may be attacked at their weak points just as readily as we attack other organisms.

The root knot nematode is a parasite which can live only in association with the roots of living susceptible plants. Although nearly 1000 species of weeds and crop plants have been listed as susceptible to root knot, there are a few crops which can be planted on infested soil. The resistant crops which may be planted on organic soils in this state include corn for grain or fodder, sorghum and millet for grain, grasses and cereals for pasture or as soiling crops, and velvet beans, crotalaria, Iron and Brabham cowpeas and beggarweed as soiling crops. When these resistant crops are grown on nematode infested soil for one or more seasons, the nematode population falls off rapidly. Vegetable growers will not find cash crops in this list and may want to try onions as a revenue producing crop for infested land. This crop, which has not had a place among Florida truck crops, may now find more favor if the Grano variety is more widely planted.

Where the farm acreage is rather large, it may be found practical to allow infested land to be fallow for one or more seasons. Just as the nematodes can be starved out by planting resistant crops, they also can be starved by not planting a crop and keeping the land free of all weeds. A system whereby the infested land is kept fallow during the winter and planting to a resistant soiling crop during the summer can be used to advantage since it is not advisable to allow the soil to be exposed to the sun during the summer. In the second year of this program it would be well to plant resistant or only slightly susceptible crops during the winter, and to follow with a resistant cover crop during the second summer.

While it is important to reduce heavy nematode infestations by the use of resistant crops or by fallowing the land, it is more important to prevent the building up of large nemic populations by poor practices. Okra, tomatoes, eggplant, snap beans, lima beans, cucumbers, peppers, squash and Irish potatoes are very susceptible crops and tend to build up the infested land, particularly during the warmer months. Where the infestation is too light or scattering to warrant the removal of the land from the production of cash crops, it would be advisable to plant only the more tolerant crops such as lettuce, cabbage, cauliflower, collards, turnips, beets, carrots, mustard and celery. These crops will succeed as winter crops, particularly where there is only a light infestation. Great care should be taken with all transplanted crops to see that

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the seedlings do not have root knot as it is very difficult for infested seedlings to recover from the shock of transplanting, and also because such seedlings would transfer the nematodes to new areas.

Environmental factors influence nematode populations and thus play important roles in the development of the root knot disease. Temperature is probably the most important of these factors. A study of the relation of soil temperature to the development of nematodes on beans has been made. It was found that the nematodes develop about twice as fast at 82° F. as they do at 70° F. Thus, if the lower temperature prevailed, there would be seven generations per year while at the higher temperature the number of generations would be fourteen. This simply means that nematodes are much more numerous and therefore more destructive in the warmer months. The fact has particular importance if susceptible crops or weeds are allowed to remain on the land from May through October. It also shows why the more tolerant crops can be grown during the cool months—or perhaps further research would show that some of the so-called tolerant crops are those best adapted to the cooler months and hence are not subject to as heavy infestations as the heat-loving susceptible crops such as okra, tomatoes and eggplant.

Nematodes may be destroyed by either drying or flooding a soil. Drying is not practical for field practice but can be employed for small amounts of infested soil in pots or flats. Soil containing larvae and eggs of the nematode can be freed of the parasite if spread to dry in thin layers for a few weeks. The larvae are killed very quickly by exposure to the sun. Flooding the soil for periods of three to six months has sometimes proven to be very helpful. Although we have no experimental data to substantiate the statements, several Everglades growers have improved seedbed lands by flooding them during the summer. Root knot of celery seedlings was very prevalent in one seedbed area in 1939 but has been of no importance since the practice of flooding the area for three months each year has been followed. Flooding of entire farms for two or three months each summer is an entirely practical procedure in the Everglades and should have beneficial results in the reduction of nematode populations.

Because there are so many successful chemical treatments for the control of insects and fungous diseases, one naturally inquires why chemical controls for nematodes are not more widely used. Prof. Watson and Dr. Miller are going to tell you about their work with chemicals and will give you the details of the better treatments. No doubt, much that they have learned about the treatment of mineral soils can be applied to the control of nematodes in organic soils. The work of Neller and Allison reported in Vol. 40 of Soil Science should also be mentioned. They made a moling device which could be attached to a garden tractor and enabled them to inject a continuous stream of chloropicrin into the soil, thereby controlling nematodes.

All of the chemical treatments which have been reported to this time require rather large amounts of expensive chemicals. The sodium cyanide and ammonium sulphate treatment cost about $150 an acre in 1930. I have no figures on its present cost. Formaldehyde is expensive and probably unattainable at this time. Chloropicrin, if available, would

cost more than $300 an acre. With these figures in mind one can readily see that these treatments can be recommended only where there is a high investment in a limited area, as in seedbeds and nurseries.

The organic soils of the Everglades can be developed for production at a cost of about $75 an acre, or developed lands can be rented for $15 an acre. These values place limits on the amount that one could afford to spend for treatments to control nematodes. Infested land can be removed from production or planted with resistant crops for a year or more at much less expense than would be required for present chemical treatments.

These remarks concerning the feasibility of chemical treatments for the extensive acreages of organic soils in Florida should not be construed to mean that chemical methods of nematode control should not be attempted in special cases. Neither should these remarks discourage research on new chemicals or on new ways of using the chemicals already available. The time may come when it would be more economic to use chemical methods of control than it is today.

The following publications deal with the nematode problem in Florida organic soils:

1. A machine for the subsurface treatment of soil with chloropicrin and with carbon bisulfide for nematode control under field conditions. By J. R. Neller and R. V. Allison. In Soil Science, pp. 173-178, Vol. 40, 1935.

2. Development of the root knot nematode on beans as affected by soil temperature. By G. R. Townsend. Fla. Agr. Expt. Sta. Technical Bul. 309, 1937.

THE NEMATODE PROBLEM FROM THE SOIL MICROBIOLOGICAL STANDPOINT

F. B. Smith and J. W. Batista *

Soil Microbiology has been defined as that branch of science which deals with the occurrence, life histories and functions of microorganisms in the soil, and *their relation to the crop-producing power or fertility of the soil.* The functions or microbiological processes ordinarily considered are ammonification, nitrification, denitrification, nitrogen fixation, sulfur oxidation, carbon dioxide production and organic matter decomposition. It is proposed here to add "Biological interactions" to this list for consideration whenever soil microbiological processes are discussed.

Biological interactions are not processes in the same sense as ammonification, nitrification and sulfofication, but treating the subject in this manner should serve to focus attention on this important relationship and emphasize the significance of various specific interrelatingships among microorganisms. Legume inoculation and mycorrhiza formation are examples of the interaction of soil microorganisms and the higher plants which have received considerable attention. However, except for the possible symbiosis of the Azotobacter with the Algae and the suggestion that soil microorganisms are responsible for the production of substances toxic to the growth of higher plants and to other microorganisms, no general theory of biological interactions has been proposed. The interactions of microorganisms in the soil and their interrelationships with the higher plants form possibly the most important function in the whole field of the science.

An extensive literature has accumulated on the interrelationships of microorganisms (15). Nearly all textbooks of a general nature on microbiology and the biological journals are replete with references concerning biological interactions. No extensive review of the literature will be made here, but it seems desirable to call attention to some of these investigations, especially those which may have a bearing on this problem.

Starkey (10) found that higher plants exerted pronounced influence upon the soil population and that different plants exerted different degrees of influence. The extent of the influence of any one plant upon the soil organisms was different at the various stages of plant growth. In a later study (12) it was found that microorganisms were much more abundant about the roots of plants than in the soil near the roots. The bacterial population and the bacteria of the Radiobacter group were affected by root growth to a much greater extent than the actinomyces and filamentous fungi. The evolution of carbon dioxide and the accumulation of nitrates were greater in soils which supported plant growth than a fallow soil (11), but the nitrification of ammonium sulfate in

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the soils did not appear to be affected by plant development to as great an extent as nitrification of the soil nitrogen.

Winogradsky (20) noted that in soils of low nitrogen-carbon ratio, the nitrogen fixing bacteria are able to attack the carbon compounds, but in the presence of nitrogen compounds the usual soil bacteria attack the carbon compounds before the nitrogen fixers can make use of them.

Waksman and Lomanitz (16) found that *Bacillus cereus* grows well in a casein medium, but *Pseudomonas fluorescens* does not attack the casein. In mixed cultures a luxuriant growth of the latter occurred.

Lewis (5) found that *Pseudomonas fluorescens* produces toxins in sterilized manured soils; these toxins could be extracted by alcohol and were able to inhibit the growth of such bacteria as *Bacillus cereus*, *Bacillus mycoides*, *Bacillus anthracis* and *Sarcina lutea*, but not of *Escherichia coli* and *Serratiea narcescens*.

Neller (9) found that a mixture of *Bacillus subtilis* and *Bacillus vulgatus* produced considerably more carbon dioxide from cottonseed meal in soil than either organisms alone but less carbon dioxide was produced by a mixture of *Bacillus mycoides* and *Bacillus megatherium* than either organism separately.

Waksman and Foster (17) found that one species of actinomyces (Actinomyces 3065) when grown on synthetic media inhibited the growth of a variety of fungi, bacteria and other actinomyces.

Waksman and Hutchings (18) made a study of the associative growth of different fungi, actinomyces and bacteria upon different plant materials and of the resultant decomposition of the latter. It was found that the presence of one organism may modify considerably the growth of another. Also the decomposition of organic matter was modified considerably by the presence of various fungi and bacteria. Some organisms unable to decompose cellulose, were capable of favoring cellulose decomposition by other organisms. Significant was the fact that lignin decomposition took place only when actinomyces were present in the mixture of organisms.

SOIL MICROORGANISMS ANTAGONISTIC TO ROOT-KNOT PRODUCING NEMATODES

It has been reported that a heavy mulch reduces root-knot injury to plants by nematodes. Watson (19) recommends the use of moderate mulches of straw, weeds or similar materials for minimizing root-knot injury by nematodes to fruit trees.

Fawcett (4) suggested the possibility of parasites as a factor in the variable serverity of infestation of the root-knot nematode *Tylenchulus semipenetrans*. He stated also that the use of suitable amounts of bulky organic fertilizer was an important factor.

Thorne (14) in a study of *Heterodera schichtii* stated that when a crop of sweet clover is plowed under the heat and gas from the decaying materials kill large numbers of nematodes, including cysts. Examination of soils treated in this way showed that the number of nematodes killed varied from 5 to 22 per cent of the total population.

Stewart, et al. (13) found fewer nematodes in the roots of sugarcane grown in soil treated with molasses than in the untreated soils. They also found in one soil that the addition of molasses was followed by an increase in the population of Mononchus, a genus of predacious nematodes.

Linford (6) found that the decomposition of large amounts of organic matter in Hawaiian soils was associated with a reduction of galls on roots of cowpeas. He stated the decomposition of organic matter results in an increase of several biologic forms destructive to nematodes, including nema-trapping fungi, funga parasites, predacious nematodes and predacious mites. These attack various types of nematodes, destroying the larvae of the root-knot type and other free living forms which comprise the greater part of the total nematode population of the soil.

Linford (7) working in Hawaii found a number of enemies of *Heterodera marioni*. He reported the finding of fifty-two enemies of this organism since 1935. Eleven were nematode-trapping fungi, (Phycomycetes and Hyphomycetes), Ancylistales and Hyphomycetes, one ectoparasitic protozoa, twenty-four predacious tardigrades (Microbiotus). He (8) also found root-knot injury restricted by *Dactilella elipsospora*, but *Arthrobotrys oligospora*, *A. musiformis*, *Dactilella* sp., and *Dactylaria thaumasis*, which are parasitic on free-living nematodes, were without apparent effect.

Dreschler found that (1, 2, 3) species of Arthrobotrys, Dactilella, Triposporium, Dactilaria, Tridentaria, Nematoctounus, Acrostolagmus, Cephalosoprium, Meria, Trichothecium, Haptoglossa, and Meristacrum, attack different forms of free-living nematodes.

Applications of organic matter to the soil stimulate microbial action and some microorganisms produce substances which retard or inhibit the growth of others. It seems possible that the beneficial effect of the mulch in reducing root-knot injury results from some metabolic by-product in the decomposition of the organic matter, to the stimulation of some organisms antagonistic to the parasistic nematode, or to an improved fertility condition which permits growth of the plant in spite of the root-knot producing nematode. The purpose of the work we are doing is to determine the role of soil microorganisms in effecting this control and to this end a number of experiments have been planned.

Preliminary tests have been made on the numbers and kinds of molds and on the numbers of bacteria and actinomyces in mulched and clean cultivated soils. No significant differences in the mulched and clean-tilled soils have been found to date.

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SOME SOIL BORNE INSECTS OF INTEREST TO FLORIDA GROWERS WITH BRIEF NOTES ON THEIR CONTROL

A. N. Tissot *

To the uninformed the soil may seem a simple thing –just a handful of earth, but to those who have studied it, the soil is recognized as an extremely complex and ever changing portion of our world. To be productive of plant growth a soil must contain mineral particles, organic substances, water and air. If a soil is productive of plant growth it will also maintain great numbers of living organisms, such as bacteria, algae, fungi, and many kinds of animals.

Of the animals which spend more or less of their time in the soil, we may mention burrowing animals, as moles and salamanders; worms, of which well known examples are the earthworms and nematodes; and insects and their relatives. The kinds and numbers of insects in the soil vary greatly from place to place, from time to time, with the vegetation growing on the soil and with the nature of the soil itself. A warm, moderately moist, fertile soil offers conditions favorable for the greatest development of insect life. A poor soil will produce limited plant growth and likewise limited insect populations, while a fertile soil with generous amounts of organic materials will contain enormous numbers of insects, varying from a few hundred thousand to several million indivduals per acre.

The kinds of insects found in the soil are extremely varied. With the exception of a few orders which are strictly parasitic or aquatic in habits, all orders of insects have soil inhabiting representatives. Those most commonly found in abundance are Collembola or springtails, Thysanura or bristle tails, Coleoptera or beetles, and Diptera or flies. Though they are not insects, mites should also be mentioned here as they too are usually present in enormous numbers. Some insects spend their entire lives in the soil, coming to the surface rarely or not at all. In this group we find such insects as springtails, and mole crickets. Others spend only a part of their life cycle, usually the immature stages, in the soil, the other stages being found above ground. Beetles, flies, and moths generally belong to this group. Still other insects, such as ants, use the soil only as a shelter, or hiding place or a place to make their nests.

The food habits of subterranean insects are extremely varied. Some feed on living plants or animals, others on dead organic matter and excrement, and still others on bacteria and fungi.

Insects are influenced by the nature and composition of the soil and they in turn affect soil reactions and plant growth. About sixty years ago Charles Darwin made careful studies and measurements of the effects of earthworms on the soil. He found that the worms incorporated organic matter with the soil, brought subsoil to the surface and in burrowing

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through the soil made it more permeable to water and air. Insects exert a somewhat similar influence on the soil. They change the physical condition of the soil by their continued movement or by passing the soil through their bodies. They cause chemical changes by their digestive processes or by their influence on soil fungi and bacteria. They devour other members of the soil fauna and flora, like algae, fungi, and protozoa and finally they may cause some damage to cultivated crops. When careful studies are made of the entire insect population of the soil, it is found that a comparatively small proportion of the species are detrimental. Another relatively small portion of subterranean insects are beneficial in their effects, while the vast majority of species are rather indifferent, with their harmful and beneficial effects more or less counterbalancing each other. To this intermediate group belong some of the predacious insects which feed on beneficial and harmful forms alike and also those insects which may be harmful in one life stage and beneficial in another. As an example of this type we may mention the blister beetles which in the adult stage often cause considerable damage to ornamentals and other cultivated plants but whose larvae burrow in the soil and feed upon the eggs of grasshoppers.

Our knowledge of soil inhabiting insects is far from complete and many species have never been studied. But even so, to attempt to call the roll of all the insects known to live in Florida soils would be a long and monotonous task. It may be well, however, to mention a few of the soil insects that are commonly destructive to cultivated plants. Mole crickets have caused a good deal of concern in many sections of the state, particularly in the area between Plant City and Sarasota. These insects spend most of their lives burrowing in the soil and coming to the surface only occasionally. The food habits of mole crickets are still rather obscure and it has not been determined to what extent they feed upon living plants. It is generally believed, however, that their greatest damage is due to the mechanical injury that they produce by burrowing under plants and breaking the small roots. They are particularly bad pests of plant beds, and a heavy infestation may cause the complete destruction of the small seedling plants.

The larvae of many beetles are soil inhabiting and some are destructive to cultivated plants. White grubs, the larvae of June bugs or May beetles, are among the most commonly found. These beetles lay their eggs in the soil and the larvae or grubs feed upon the roots of grasses or other plants. They are more prevalent in soils having an abundance of organic material and a heavy application of barnyard or dairy manure is likely to produce an infestation of these insects. Many of the leaf eating beetles, such as flea beetles and cucumber beetles have soil inhabiting larvae that feed upon the roots of plants. The click beetles constitute still another group with destructive larvae. Their larvae commonly known as wireworms are so called because of their long, slender, and hard shelled bodies. They too feed upon the roots of plants, often mining the larger roots, and sometimes tunneling completely through the tubers of Irish potatoes.

In the Lepidoptera, we find very few soil inhabitants among the butterflies, but the pupae and larvae of many moths are found in the

soil. The cutworms constitute a rather common and particularly destructive group. Mostly, they use the soil for shelter and protection from their enemies, coming above ground to feed. Cutworms are especially destructive to newly set herbaceous plants which they cut off at or near the surface of the soil. Other cutworms feed upon the foliage of plants and a few even climb trees to feed.

The larvae of many Diptera or flies are found in the soil but they are mostly scavengers and do not commonly attack living plants. There are a few exceptions, however. About two years ago the seed corn maggot was prevalent in several sections of the state and caused appreciable damage to cucumbers, beans, lupines, and other plants.

Hymenoptera are represented among the soil inhabiting insects by ants and several species of burrowing bees and wasps. Ants are particular pests of plant beds because of their habit of carrying small seeds to their nests to be used for food. Others bite off pieces of plants and carry them underground to be used in their mushroom cellars. They may become a nuisance in still another way, by biting or stinging people and thus interfering with their work. No attempt will be made to discuss in detail the control of the various soil insect pests but this phase of the subject will be dismissed with a few rather general remarks. Mole crickets and cutworms are best controlled by the use of poison baits. These baits ordinarily consist of bran or other feed as a carrier and an arsenical or fluorine compound as the killing agent. Other materials sometimes are added to the baits to render them more attractive to the insects. White grubs sometimes are controlled by incorporating lead arsenate with the soil at the rate of 5-7 pounds to 1000 square feet of surface. There is no effective method of poisoning wireworms but they can sometimes be trapped by burying in the soil bunches of leafy vegetables and then examining these at intervals of a few days and destroying the larvae that have collected to feed. Ants can be controlled by means of poison baits, which are generally available everywhere. They may also be destroyed in their nests by means of carbon bisulfide, cyanide or other fumigants.

Perhaps it may be well to say a few words concerning the effects upon soil insects of the various methods of soil sterilization commonly used against nematodes. Steam sterilization, if properly done, will completely rid the upper layers of the soil of all insect life but some deep burrowing forms, such as mole crickets and white grubs, may escape this treatment. The different soil fumigants may have varying results on soil insects. A particular insect stage may be relatively resistant to some fumigants and quite susceptible to others. For instance, the egg in some insects is the stage most resistant to chloropicrin but the least resistant to ethylene oxide and hydrocyanic acid. In general we can safely say that a material which will effectively rid the soil of nematodes can be pretty well depended upon to destroy most insect life also. Insects, however, are capable of rather rapid dispersal and the treated area may quickly become reinfested, particularly if it is small.

SOIL-BORNE DISEASES AND SOME METHODS OF CONTROL

Erdman West

Any attempt to discuss all the soil-borne fungous diseases of Florida crops in a ten minute talk would be utterly foolish. Inasmuch as this symposium is interested primarily in nematodes and their control, I shall try to limit my brief remarks to the phases of my subject that may be related to that field of endeavor. For convenience in this discussion the fungi causing soil-borne diseases will be grouped in general, according to the symptoms they produce on the host plants or crops.

DAMPING-OFF

Damping-off is a broad term applied to diseases which kill seedlings before or soon after they emerge from the soil in the seedbed or field. They are especially vicious because they work rapidly and much damage is done often before their presence is noticed. They result in heavy losses of valuable seed stocks and in wasted fertilizer and labor expenditures by causing poor stands. Among the fungi responsible for this sort of trouble are:

Rhizoctonia species. There are many forms of this which may be varieties of *Corticium vagum* Berk. or perhaps distinct species.
Sclerotium rolfsii Sacc.
Pythium spp.
Phytophthora spp.
Fusarium spp.
Macrophomina phaseoli (Maubl.) Ashby (*Sclerotium bataticola* Taub.)
Bacteria.

The control of damping-off involves the use of several different procedures. The treatment of the seed before planting is widely used to prevent pre-emergence damping-off. For this purpose several different chemicals are in use. This sort of treatment is not of interest here because it can have little or no effect on nematode infestation.

Soil treatments for the control of damping-off may consist of chemicals as dusts or in solution while plants are growing, or sterilization by some means before the seeds are sowed or the plants set. In the presence of living plants, certain salts of mercury, zinc and copper are in common use but their effect on nematodes is negligible. The specific chemicals and procedures used are not important in this discussion.

Soil sterilization in the absence of living plants has been a standard method of controlling damping-off, particularly in small areas or under glass. Several of the methods used are also effective against root-knot producing nematodes. The use of live steam is probably the oldest method in this general category. Small amounts of soil may be sterilized under pressure in a suitable container, larger amounts such as green

house benches by the use of buried perforated pipes and seedbeds and large areas out-of-doors by inverted pans and a mobile steam boiler. Later a mixture of steam and formalin was used. Of late years a solution of formaldehyde alone has been widely used and is still one of the most satisfactory methods of sterilizing soil.

With the spread of cotton root rot in the southwest, new methods of soil sterilization, particularly those adapted to field conditions, were evolved and tested. One of the most promising is the use of tear gas or chloropicrin. While unpleasant for the operator to use because leak-proof applicators are hard to make, the results have been gratifying. Improved hand applicators have been devised and at least one machine developed for field use. Much experimental work has been conducted with this chemical in various parts of the United States and its effectiveness as a soil disinfectant for damping-off fungi has been demonstrated.

Other chemical soil disinfectants useful under certain circumstances are ethyl mercury iodide, ethyl mercury phosphate and ethylene dichloride. Organic mercury salts are not available under war conditions and are not desirable because they are dangerous to the operator.

In general, soil sterilization by any of the means listed for the control of damping-off fungi is more or less effective for the control of the root knot nematode.

WILT DISEASES

Wilt diseases are most serious under field conditions where expensive soil sterilization or other treatments are not practical. Fusarium wilt of such crops as tomato, watermelon, cotton and aster are usually combated by the use of resistant varieties. There has been little work done on the correlation of wilt-resistance and root-knot infestation, though it has been proved that Fusarium wilt infects more plants when root knot infestations are present. It may be possible to breed strains of such crops resistant to both Fusarium wilt and root knot nematode.

Bacterial wilt is common on several crop plants such as potato, tomato, pepper, eggplant and tobacco but it also occurs on other plants, including many of our native weeds. Crop rotation is of little benefit and resistant varieties are not known, except in potatoes. Reducing the hydrogen-ion concentration of the soil for a time by the use of sulfur and raising it again later by the application of proper amounts of lime has proved to be very effective in the control of this disease. What effect this has on the nematode population, I do not find reported.

OTHER SOIL-BORNE DISEASES

There are many other soil-borne disease of importance in Florida that would require many hours to discuss. I shall refer briefly to a very few of them.

Pink rot of celery is a serious disease that can be controlled by the use of calcium cyanamid. The chemical is applied to the infested soil after the land has been cleared of the previous crop and then the ground is flooded. This not only eliminates the fungus from the soil but cuts down the amount of fertilizer necessary to produce the following crop.

Since cyanamid is one of the chemicals recommended by Watson for the control of root knot, its use has a three-way advantage.

Mushroom root rot of tung oil and many other woody plants in the State has not yielded to any method of control tried.

Fusarium rot of gladiolus has not been controlled satisfactorily by any treatments or procedures yet devised. Whether or not nematode complicate infection and control of this trouble is not known.

In summarizing our brief discussion of soil-borne diseases in Florida with special reference to the problem of nematodes, two points appear:

1. There are many soil-borne diseases in Florida for which the effective treatment will also at least reduce the nematode population.

2. The further investigation of the relationship of fungus control to nematode control seems likely to yield worthwhile returns.

BANQUET AND BUSINESS MEETING

Dr. J. R. Neller, Presiding

A business meeting was called at 8:15 p.m. following the Annual Banquet held in the Whitehouse Hotel, Gainesville. The first order of business was a very interesting lecture by Dr. G. Steiner, Nematologist of the U. S. Department of Agriculture, on the subject "Nematodes and the Life Association of the Soil." The complete text of the lecture appears at the front of this volume where Dr. Steiner is properly acknowledged as the guest speaker of the Society.

The reading of the minutes of the past meeting was dispensed with.

APPOINTMENT OF AUDITING COMMITTEE

The auditing committee of the past year, Mr. R. A. Carrigan, Chairman, and Mr. G. H. Blackmon and Dr. R. B. Becker, was continued and instructed to examine the financial records of the Society and report.

REPORT OF THE TREASURER TO THE AUDITING COMMITTEE

For the Period December 1, 1941 to December 15, 1942

This is the first report of the Treasurer since the activities of the Society were changed to the calendar year basis which provides that the regular annual meeting of the Society should fall late in the year. With the permission of the Executive Committee, the Treasurer would like, in the future, to close the books on December 31 and have the report officially audited at that time for publication in the Proceedings.

The receipts for the year have been considerably amplified by special grants in aid during the year from the State Department of Agriculture, from the Everglades Drainage Board, and from the U. S. Sugar Corporation, also from forty-six (46) other sustaining memberships varying in amounts between $10 and $25. These items were largely in support of the publication of the first section (A) of the Fourth Proceedings to cover the Everglades meeting held in West Palm Beach on April 21. This report is now in press.

With regard to the collection of annual dues for 1942, those of 359 members are outstanding. However, this is appreciably less than half of the total number of notices that were sent out. Against this, sixty-one have paid their dues for 1943, three for 1944, and one gentleman from South America has plunged forward to and including 1947. This is indeed a fine example of good neighborliness. It is anticipated that at least one-half or more of the above number now delinquent will be lost, at least for the duration of the war and the unsettled conditions that follow.

Insofar as the present balance is concerned, it must be remembered that there is involved the full cost of publishing and distributing three volumes of the Proceedings—the Third and two volumes of the Fourth—as well as the general expenses of the present meeting. On this account it will be important to interest as many new members as possible in the

work of the Society during the coming year to replace the unavoidable losses which we are facing.

A brief report of the status of the treasury of the Society as of December 15, 1942 follows:

RECEIPTS	
Balance in bank, Dec. 1, 1941	$1012.21
Total receipts Dec. 1, 1941-Dec. 15, 1942	1729.92
Total	$2742.13
EXPENDITURES Dec. 1, 1941-Dec. 15, 1942:	
Printing	$ 846.82
Postage	87.40
	$ 934.22
BALANCE ON HAND (IN FIRST NATIONAL BANK, GAINESVILLE) Dec. 15, 1942	$1807.91*

* Includes cost of publishing Volume III and IV-A of the Proceedings as well as that of present meeting, Vol. IV-B.

Examined and Approved by the Auditing Committee:

Signed: Dr. R. B. Becker
Mr. G. H. Blackmon
Mr. R. A. Carrigan, Chairman

REPORT OF THE EDITOR

The Third Proceedings definitely will be available in the near future as will also the First Part of the Fourth Proceedings, Volume "A" which is in press at the present time and dedicated to Governor Holland for the valuable part he played in refinancing the Everglades Drainage District. The meeting also played a very important role in the coordination of the Everglades work. As such the Proceedings will prove a valuable record to serve as a basis for future activities in this field.

ELECTION OF OFFICERS

The Nominating Committee, which had been appointed at the close of the morning meeting by President Neller, and consisting of Dr. W. T. Forsee, Mr. J. R. Henderson and Mr. H. A. Bestor, was requested to report. The Committee nominated a single candidate for Vice-President in the person of Mr. G. M. Volk and the motion of the Chairman that the nominations be closed and the Secretary instructed to cast a unanimous ballot was promptly seconded and unanimously carried.

INSTALLATION OF OFFICERS

Following the election, Vice-President Mossbarger was inducted into the office of President by Dr. J. R. Neller who by this change automatically became a member of the Executive Committee.

MEETING OF EXECUTIVE COMMITTEE
Decemrer 18, 1942

The meeting was called immediately following the Business Meeting at the Hotel Whitehouse, President H. I. Mossbarger presiding. The following items of business were discussed and acted upon.

1. Spring meeting for a further discussion of soil and water conservation problems in South Florida. Action favorable and early initiatives of planning for same strongly advised.

2. The appointment of Dr. Wilson Popenoe as Chairman of the Tropical Soils Committee. Action favorable and the Secretary instructed to advise Dr. Popenoe of his responsibility in this connection.

3. The proposal to ask Prof. John Fletcher Martin to act as Spanish Editor for the Proceedings of the Society. Action favorable and the Secretary was instructed to advise Prof. Martin of the sincere appreciation of the Society and its Executive Committee for his willingness to help the work along in this fine manner.

4. The appointment of assistance for the Secretary-Treasurer of the Editor at the discretion of this official. Action favorable especially with the view of extending the membership of the Society somewhat to take up the losses occasioned by present conditions as referred to in the report of the Treasurer.

5. R. V. Allison was named to fill the position of Secretary-Treasurer for another year.

There being no further business the meeting adjourned at 10:45 p.m.

RESOLUTIONS

A Resolution of Thanks to the Officials of the Bureau of Plant Industry for Their Forethought in Making the Services of Dr. G. Steiner and Mr. A. L. Taylor Available for Discussions of and Conferences on Florida's Nematode Problem

Whereas, the nematode problem in all its ramifications, is one of the most serious facing all types and classes of growers in Florida, and

Whereas, Dr. G. Steiner, Chief of the Division of Nematology, Bureau of Plant Industry, U. S. Department of Agriculture and his associate, Mr. A. L. Taylor, stationed at the Coastal Plains Experiment Station, Tifton, Georgia, are outstanding authorities in this field, and

Whereas, funds and facilities for travel are exceedingly meager and difficult at this time.

Now, Therefore, Be it Resolved that the Soil Science Society of Florida, in regular session, record its deep appreciation of the action of the Officials of the Bureau of Plant Industry in making the valued services of Dr. Steiner and Mr. Taylor available for the discussion of this problem and consultation with Florida Research Workers and Growers, and

Be It Further Resolved that this resolution be spread upon the minutes of the Society and that a copy thereof be sent to Dr. R. M. Salter, Chief of the Bureau of Plant Industry, U. S. Department of Agriculture; to Dr. J. J. Tigert, President of the University of Florida; to the Honorable Nathan Mayo, Commissioner of Agriculture, State of Florida; to Dr. Wilmon Newell, Director of the Florida Agricultural Experiment Station and Extension Service; and to Dr. H. H. Hume, Dean, College of Agriculture.

W. F. Therkildson
Chairman, Resolutions Committee

Gainesville, Florida
December 18, 1942

SOIL SCIENCE SOCIETY OF FLORIDA

GAINESVILLE, FLORIDA
December 28, 1942

Dr. R. M. Salter, Chief
Bureau of Plant Industry
U. S. Department of Agriculture
Washington, D. C.

Dear Dr. Salter:

Under the instructions of the Chairman of the Executive Committee of the Society, I am sending you herewith a resolution of thanks adopted by the Society in regular session here in Gainesville on Friday evening, December 18.

Please do not regard this as the exercise of a routine obligation on our part since, at best, it expresses only in a poor way the real feelings of appreciation we have for the fine contributions Dr. Steiner and Mr. Taylor made to the meetings of the Society at that time.

When your bureau can send men with qualities of leadership and understanding of a particular field of research such as Dr. Steiner possesses, out for conference in this way with State research workers and others, we feel it is the finest contribution you can make to our work since it constitutes a real unit in the broad structure of effective coordination in the whole field of agricultural research which is so badly needed and which can be developed successfully and maintained effectively only by the Department.

Sincerely yours,
R. V. ALLISON
Secretary-Treasurer

RVA/D
Enclosures

J. R. NELLER

OFFICERS OF THE SOCIETY

1942

J. R. NELLER ..... President
Belle Glade

H. I. MOSSBARGER ..... Vice-President
Miami

F. B. SMITH ..... Member Executive Committee
Gainesville

R. V. ALLISON ..... Secretary-Treasurer
Gainesville